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A COMPUTER MODEL INVESTIGATION
OF A QUAD LOG-PERIODIC ARRAY

by

Cosmas Christidis

December 1988

Thesis Advisor Richard W. Adler

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This thesis investigates the possibility of developing a quad log-periodic array for use in military applications over a wide range of frequencies. The investigation of a uniformly periodic quad array was conducted utilizing the Numerical Electromagnetics Code (NEC). A numerical-experimental study of near field characteristics and far field radiation patterns for selected versions of the structure helped to identify necessary performance characteristics of a successful log-periodic version of the antenna.

The near field investigation provided k versus β information for a Brillouin diagram (β was determined from the relative amplitude and phase of the near magnetic field created by the structure under various conditions). Far field radiation patterns provided a check on the results of the Brillouin diagram and identified the presence of end or truncation effects.

The results of this study show the potential exists for designing a successful quad log-periodic antenna. Using NEC, a selected model was run in free space to obtain radiation patterns and element currents on the array. The NEC results indicate that a quad log-periodic array with a switched transmission line has desirable log-periodic characteristics and shows promise for military and commercial applications.

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A COMPUTER MODEL INVESTIGATION OF A QUAD LOG-PERIODIC ARRAY

by

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Submitted in partial fulfillment of the
requirements for the degree of

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December 1988

ABSTRACT

This thesis investigates the possibility of developing a quad log-periodic array for use in military applications over a wide range of frequencies. The investigation of a uniformly periodic quad array was conducted utilizing the Numerical Electromagnetics Code (NEC). A numerical-experimental study of near field characteristics and far field radiation patterns for selected versions of the structure helped to identify necessary performance characteristics of a successful log-periodic version of the antenna.

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I would also like to dedicate this thesis to my wife Sophia and my daughter Wemmara-Kleo, who relieved me of many family obligations during the final stretch and made it all worth it.

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I. INTRODUCTION

A. MILITARY COMMUNICATION PROBLEMS AND THE DEVELOPMENT OF A QUAD ANTENNA

For coordination and control of today's advanced technology, military forces depend on reliable communications. Military High / Very High / Ultra High Frequency (HF/VHF/UHF) communication systems provide different types of short, medium, and long range communications capability. These different requirements necessitate finding a solution to meet all of these needs. Thus the demands of military and commercial communications create a unique problem for the antenna engineer.

In designing antenna systems for military communications, the engineer has to consider a wide range of operating frequencies (2-500 MHz). Thus the engineer has to understand the conditions under which the antenna will operate, and then optimize the system performance for those conditions.

To obtain a useful antenna design, the engineer must achieve a balance between meeting operating conditions and acceptable system performance with that of space and cost limitations. As a result, it is often desireable to design antennas which have almost identical operational characteristics over a wide range of frequencies.

The original quad antenna, was introduced in the late 1940's by a radio amateur, Moore, W9LZX. It consisted of two one-wavelength loops, one loop as the driven element, and the other as a reflector as shown in Figure 1 . Later development added more loops as directors with claims of providing gains of approximately 2 dB over a Yagi of the same array length. In Moore's antenna, the loops are very sensitive to the operating frequency and consequently limit the bandwidth of the antenna. The bandwidth of a quad antenna can be increased by replacing the reflector loop element with a flat ground plane. The performance of this antenna is similar to that of a dipole over a ground. Further increases in the operating bandwidth can be achieved by arraying two one-wavelength loop antennas as shown in Figure 2 . This antenna has better characteristics in terms of bandwidth, gain, and VSWR than the original one [Ref. 1].

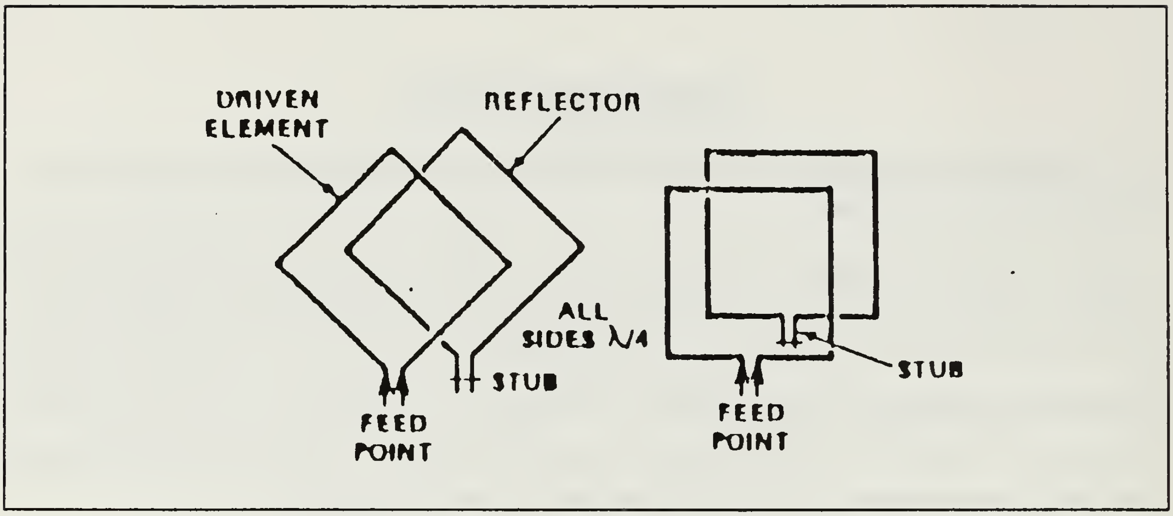


Figure 1. Quad Antenna Introduced by Moore

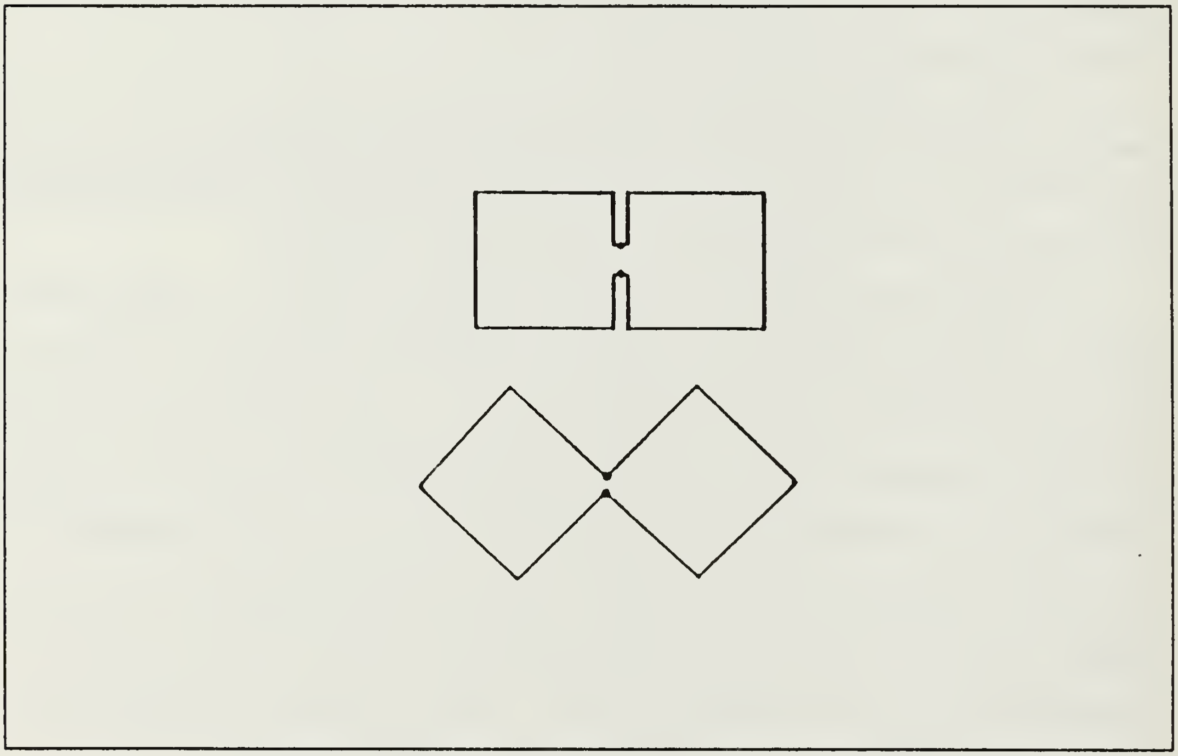


Figure 2. Two types of Bi-loop Antennas

The conventional method of connecting the elements (one wavelength square loops) in a Quad Log-Periodic Array (QLPA) through a single transposed transmission line has been reported as suffering from high VSWR. This deficiency was reportedly solved by Collins Radio Company by feeding the loops with two transmission lines situated on opposite sides of the loop and connected in parallel at the driving point [Ref. 2].

Figure 3 illustrates the basic QLPA while Figure 4 is an improved method of feeding the QLPA (staggered feed). Each element is fed on one side ("bottom") while the feed to the next element is taken from the opposite side (top). The transmission line is not tranposed. This method has been reported to give better VSWR properties and more uniform gain than the basic QLPA [Ref. 2].

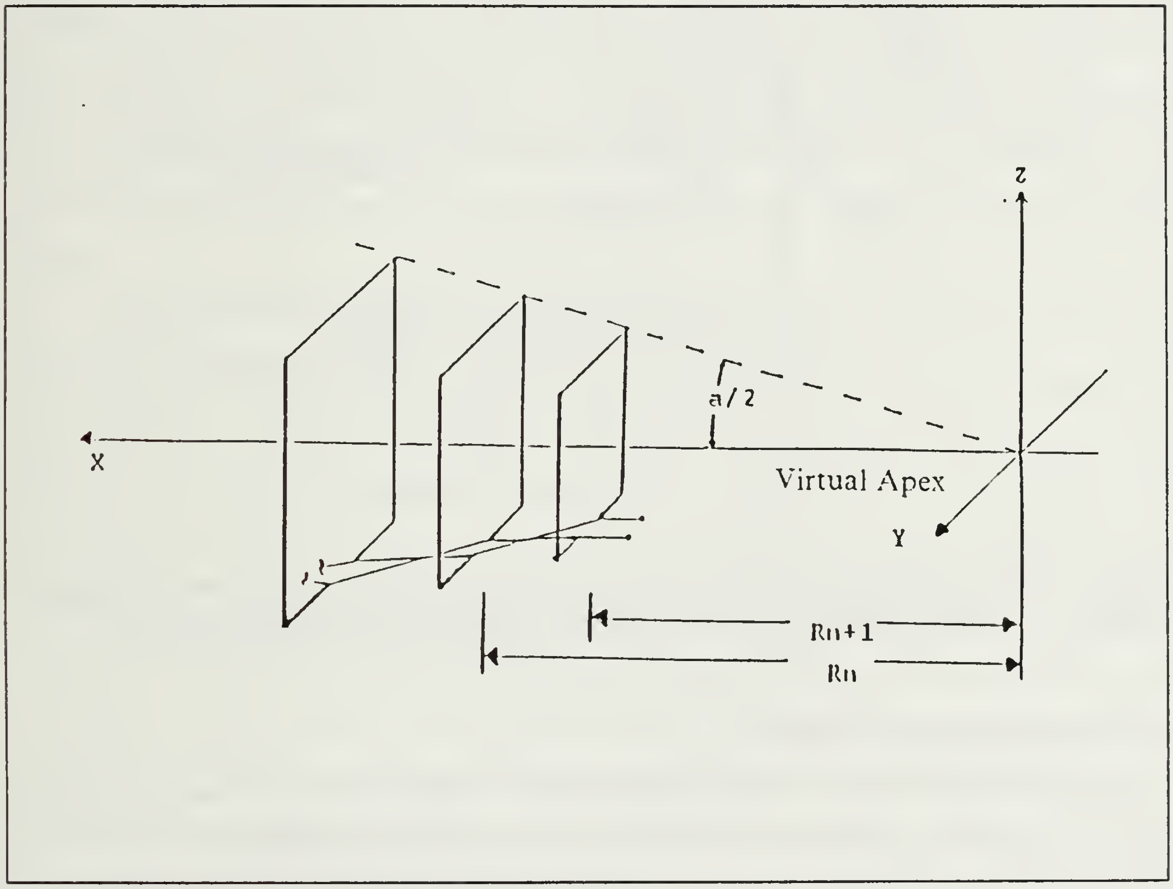


Figure 3. Basic Quad Log-Periodic Antenna

The focus of this paper is to provide more information about the design of a Quad Log-Periodic Antenna using the results of near field characteristics of Uniform Periodic Arrays (switched, unswitched and staggered feeds), and its potential as a military wideband antenna.

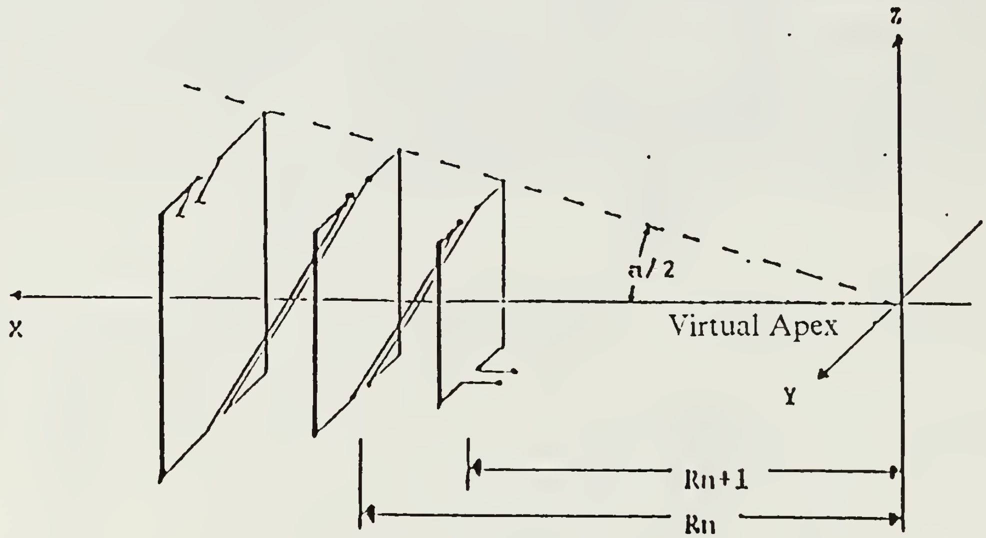


Figure 4. Quad Log-Periodic Antenna with Improved Feed (Staggered Feed)

B. BROADBAND ANTENNAS

In many applications an antenna must operate effectively over a wide range of frequencies. Generally an antenna with wide bandwidth is called a broadband antenna. Let f_c be the center (or design) frequency and f_u and f_l be the upper and lower frequencies of operation respectively for which satisfactory performance is obtained. Then the bandwidth is defined as

$$\frac{f_u}{f_l} \tag{1.1}$$

Bandwidth is also defined as a percent of the center frequency as

$$\frac{f_u - f_l}{f_c} x100\ \% \tag{1.2}$$

The bandwidth of wide band antennas is usually expressed as a ratio using equation (1.1) and narrow band antennas are quoted as a percent of the center frequency using equation (1.2) [Ref. 3].

In practice, an antenna is considered to be broadband if the specified polarization, radiation patterns, or impedance are retained over more than an octave.

C. DEVELOPMENT OF A LOG-PERIODIC ARRAY

During the period from 1955 to 1958, research was carried out, mainly at the University of Illinois, to develop antennas whose performance is almost independent of frequency. The work was sponsored by the United States Air Force in order to relieve the problems associated with the increasing number of different electromagnetic systems and equipment being carried on high speed military aircraft. It was recognized that the problem would be relieved if a given antenna could serve several systems and frequencies.

Professor V.H. Rumsey, then antenna laboratory director, realized that the "characteristic length" of the structure as compared to the operating wavelength introduced the frequency dependence. Generally, antenna performance with regard to both radiation pattern and input impedance is a function of length/wavelength. On the other hand, by the principle of modeling or scaling, it is only necessary to scale the size of the structure in the ratio of frequencies, in order to ensure that a given structure has the same performance at different frequencies. Thus, Rumsey concluded that the absence of characteristic length is the feature required for frequency independence and that the structure should be completely described by angles. Thus, he put forward the "angle concept", which is that a structure whose shape is defined by angles alone, with no characteristic length, should be a frequency-independent structure [Ref. 4]. Structures which can be described by angles alone, normally have an infinite length. Examples are the infinite biconical antenna and the infinite bifin (bow-tie) antenna. However, practical versions of these structures are obviously finite in size. Although these structures have comparatively broadband tendencies, the truncation to a finite size introduces a characteristic length property which eliminates the predicted frequency independent behavior.

Many different kinds of structures were tested which met this anglular concept requirement. In all cases the bandwidth was limited because of truncation effects, i.e., the currents were not negligible at the point of truncation.

Raymond DuHamel (then a research assistant professor at the University of Illinois) continued research on designing a broadband antenna with linear polarization. He realized, that if the currents on the structure fall off with distance from the feed point more rapidly than usual, then they could be neglected at the point of truncation. His method of accomplishing this was to introduce discontinuities into the structure. For example, he used teeth in an attempt to increase the radiation and speed up the decay of current. Discovering that the teeth increased current decay in the structure, the investigation continued into the question: "How should the teeth be designed?" He decided to follow Rumsey's angle concept as far as possible during design of this structure. He cut the teeth along circular arcs and let the length of the arcs be determined by an angle, as shown in Figure 5 .

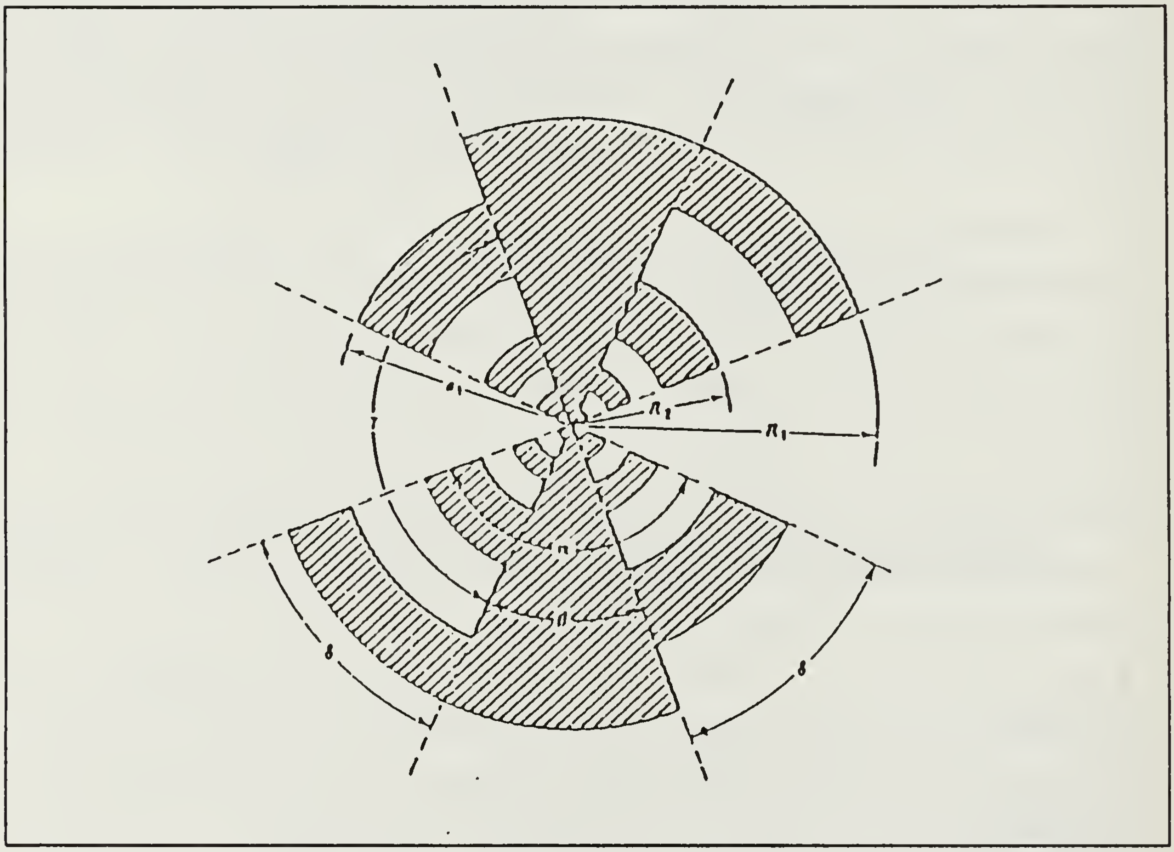


Figure 5. Log-Periodic Toothed Structure [Ref. 3]

However, this did not fix the tooth spacing, since the latter could not be specified by angles alone. In trying to solve the spacing problem, DuHamel noticed that on the successful equiangular spiral structure, along a line drawn from the center outward, the spacing from one conductor to the next was in a constant ratio. Therefore, the decision was made to cut teeth along circular arcs with a constant spacing ratio, τ:

$$\tau = \frac{R_{n+1}}{R_n} \qquad (1.3)$$

He also expected that the structure would not necessarily be frequency independent, because the finite length still created a characteristic length, which eliminated the posibility of achieving complete frequency independence. DuHamel observed that the antenna demonstrated performance in a periodic relationship to the operating frequency, and concluded that the antenna's performance was virtually identical for frequencies related logarithmically as:

$$\log f_{n+1} = \log f_n + \log f(\frac{1}{\tau}) \qquad (1.4)$$

or

$$f_n = f_{n+1}\tau \qquad (1.5)$$

The slot width is given by

$$\sigma = \frac{a_n}{R_n} \qquad (1.6)$$

These relations are true for every n. The scaling factor τ gives the period of the antenna. The frequencies f_{n+1} and f_n lead to identical performance so the antenna is logarithmically periodic [Ref. 3].

In other words, the frequencies at which the performance is the same are spaced equally when plotted on a log scale. Thus, these types of structures were named "log-periodic" antennas. All log-periodic antennas have this property.

D. THE LOG-PERIODIC DIPOLE ARRAY

After DuHamel's finding, many structures of this type were built and tested. Some of them were less successful than others.

The next major step came with Isbell's invention of the log-periodic dipole array (LPDA), an array of parallel wire dipole elements of increasing length outward from the apex feed point [Ref. 5]. He used a parallel load with switched phase from one element to the next. The length of the element was determined by an angle α as before, and the spacings were such as to give the log-periodic type of behavior.

Thus

$$\tau = \frac{L_{n+1}}{L_n} = \frac{d_{n+1}}{d_n} = \frac{R_{n+1}}{R_n} \tag{1.7}$$

and

$$\sigma = \frac{d_n}{2L_n} \tag{1.8}$$

That is, successive distances between the apex and the elements were in a constant ratio, τ, as shown in Figure 6 .

The experiments showed that the structure was indeed a broadband log-periodic structure with a unidirectional pattern. Isbell also demonstrated experimentally that most of the radiation was coming from those dipole elements which are in the vicinity of a half wavelength long and the currents and voltages at the large end of the structure were negligible within the operating band of frequencies. Finally, it was shown once again, that the operating band of frequencies was bounded on the high side by frequencies corresponding to the size of the smallest element and on the low side by the frequencies at which the largest dipole element is about a half wavelength long.

R.L. Carrel made a very careful and extremely valuable analysis on the LPDA [Ref. 6]. The analysis consisted of breaking the overall problem into parts, each of which was programmed for a digital computer. Having developed a systematic computer program, Carrel completed the calculations on more than 100 different log-periodic dipole designs. Then, he compared the results of several of these with corresponding experimental models. The measurements included not only radiation patterns and impedances but also the current and the voltage distributions on the structures. The agreement between the values of current calculated by Carrel and the values measured along the structure proved to be within experimental accuracy, and led the engineering community to accept his analysis of the dipole structure. Carrel's work provided a set of design curves which show how to adjust the dimensions of a structure in order to meet specified design objectives. Carrel's experimental values and results are shown in Figure 7 .

The pattern, gain, and impedance of an LPDA depend upon the design parameters σ and τ. The LPDA is a very popular broadband antenna of simple construction, low cost, and further details on the design are available in the literature.

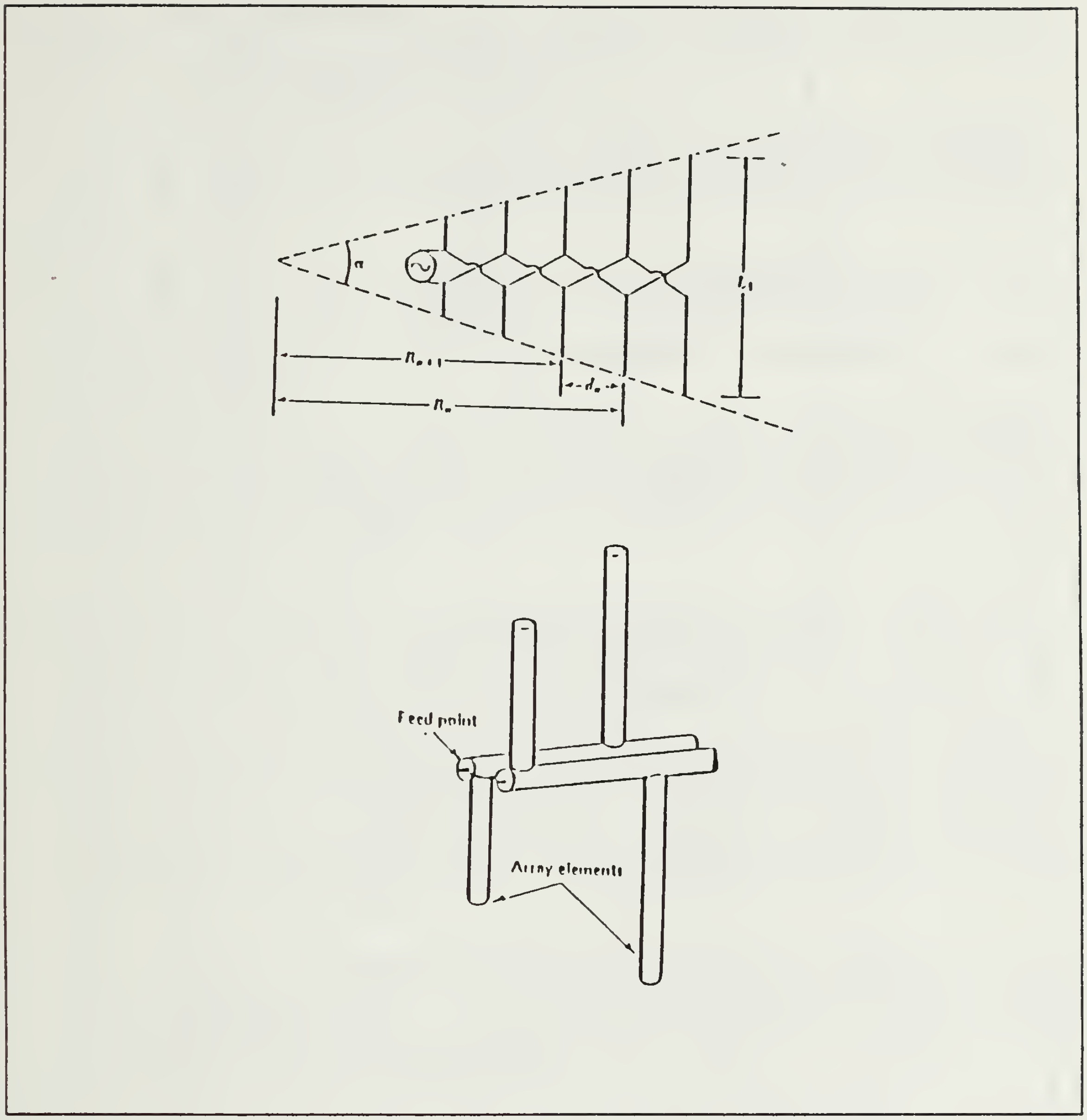


Figure 6. Log-Periodic Dipole Array [Ref. 3]

E. GENERAL CHARACTERISTIC OF SUCCESSFUL LOG-PERIODIC ANTENNAS

There are some general characteristics of successful log-periodic structures taken from experimental results. Some of them can be summarized as follows:

1. By definition, the electrical properties must repeat periodically with the logarithm of the frequency to help ensure broadband performance. To maintain frequency independence, the electrical properties must vary only slightly over a period, and

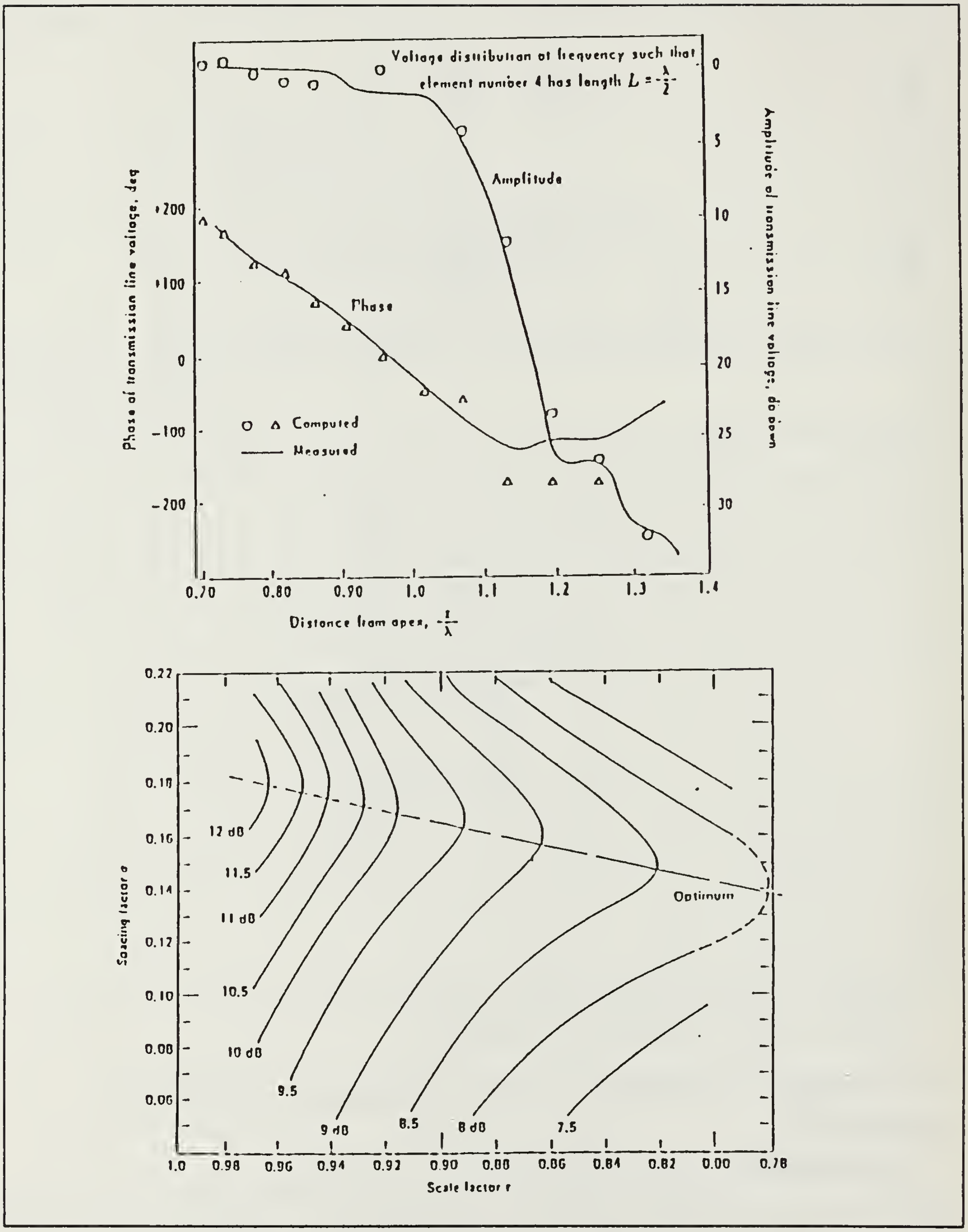


Figure 7. Carrel's Curves and Experimental Values [Ref. 3]

the structure must demonstrate a rapid decay in current over an active region or region of propagation. This eliminates end effects caused by truncation of the electrical length of the structure [Ref. 7].

2. The impedance is a logarithmically periodic function of frequency. In other words, if a plot is made of the input impedance as a function of the logarithm of the frequency, the variation will be periodic. Radiation patterns vary in the same manner, along with such parameters as the beamwidth, directive gain, and side-lobe level [Ref. 8].

3. It has been shown in previous work that the periodic relationship appears to be a necessary, but not sufficient condition to ensure broadband performance.

4. Excitation of the structure is from the high frequency or small element to the low frequency or large end.

5. There is an active region from which the antenna radiates substantially because of a proper combination of current magnitudes and their phases. The position and phasing of these radiating currents produce a maximum radiation field in the backward direction and a very small radiation field along the surface of the structure in the forward direction.

6. Backward wave radiation is another characteristic observed in successful log-periodic structures. In the case of unidirectional radiators backfire radiation occurs when the antenna "fires" through the small part of the structure, and the radiation in the forward direction is zero or very small. For bidirectional structures the backfire requirement is replaced by a requirement for broadside radiation. In other words, if the structure is excited with a wave traveling on the transmission line from left to right, backward radiation will occur if the magnitude of the current sharply decays as it travels across the left-most element of the active region. In addition the phase of the current in the right elements must lead the phase of the left elements. In all of the above cases, the radiation is in the forward direction along the surface of the structure which theoretically extends to infinity and must be zero or very small.

7. There is an inactive or reflection region beyond the active one. All successful frequency independent structures must exhibit a rapid attenuation of current within and beyond the active region. This operation will not be affected by truncation of the structure. A major cause of the rapid current attenuation is the large radiation of energy from the active region [Ref. 8].

8. A transmission region is formed by the inactive portion of the strucure between the active region and the feed point. This transmission line should have the proper characteristic impedance and negligible radiation.

General amplitude and phase relationships along with the resulting radiation patterns are shown in Figure 8.

Typical amplitude and phase relationships from backward radiation regions of loop and quad arrays are shown in Figure 9 and Figure 10 .

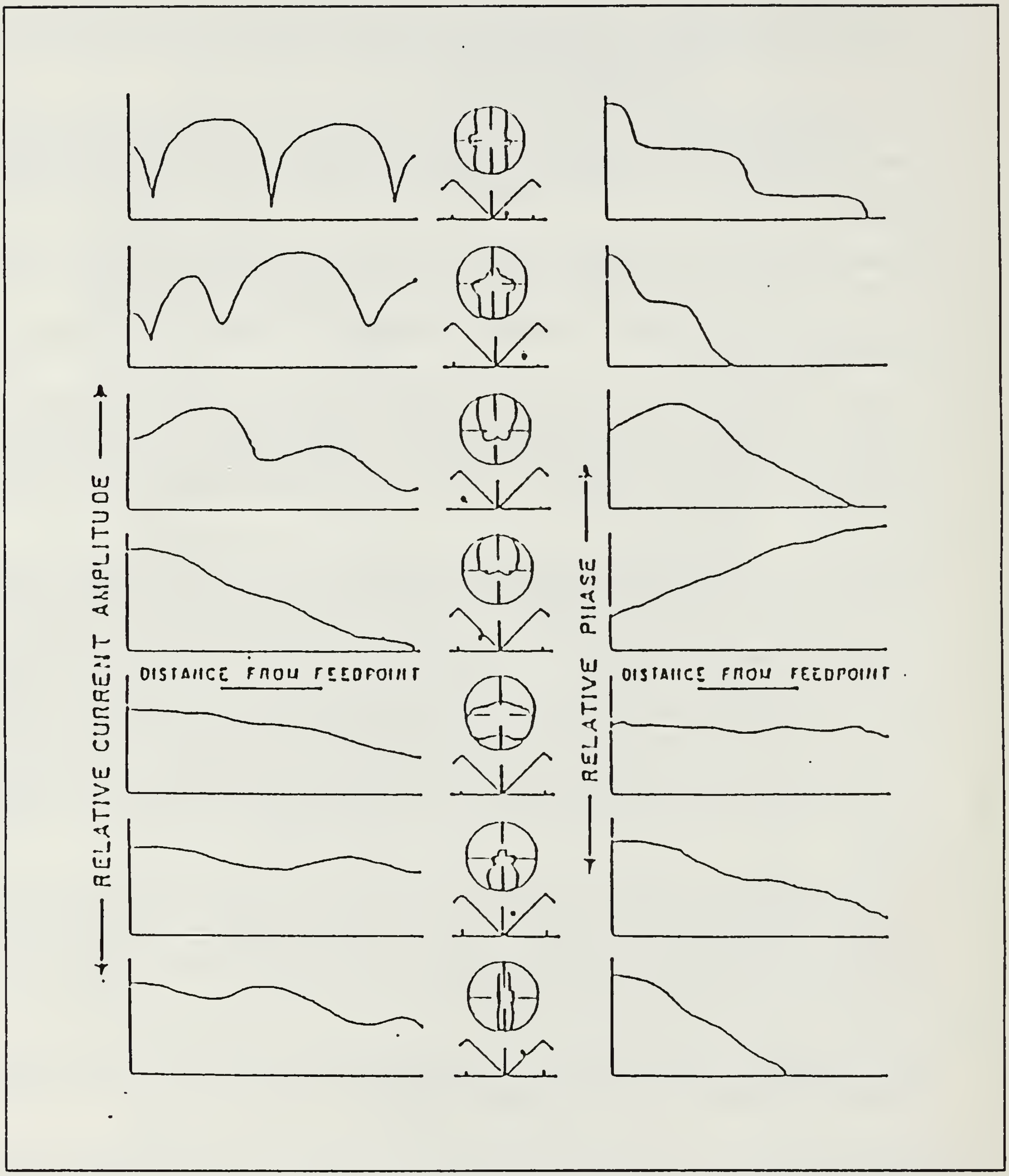


Figure 8. Amplitude and Phase Relationships for Various Areas of the Radiation Regions [Ref. 7]

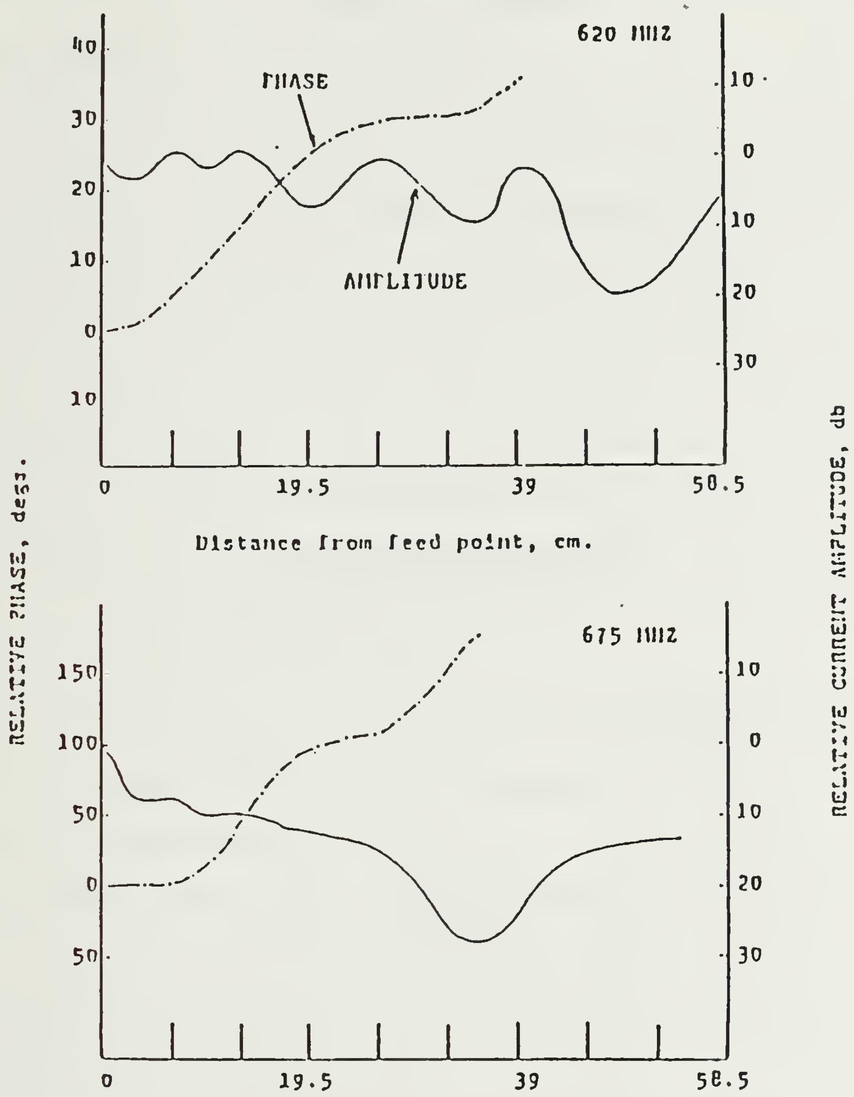


Figure 9. Current Amplitude and Phase in the Backward Radiation Region of a Loop Array [Ref. 10]

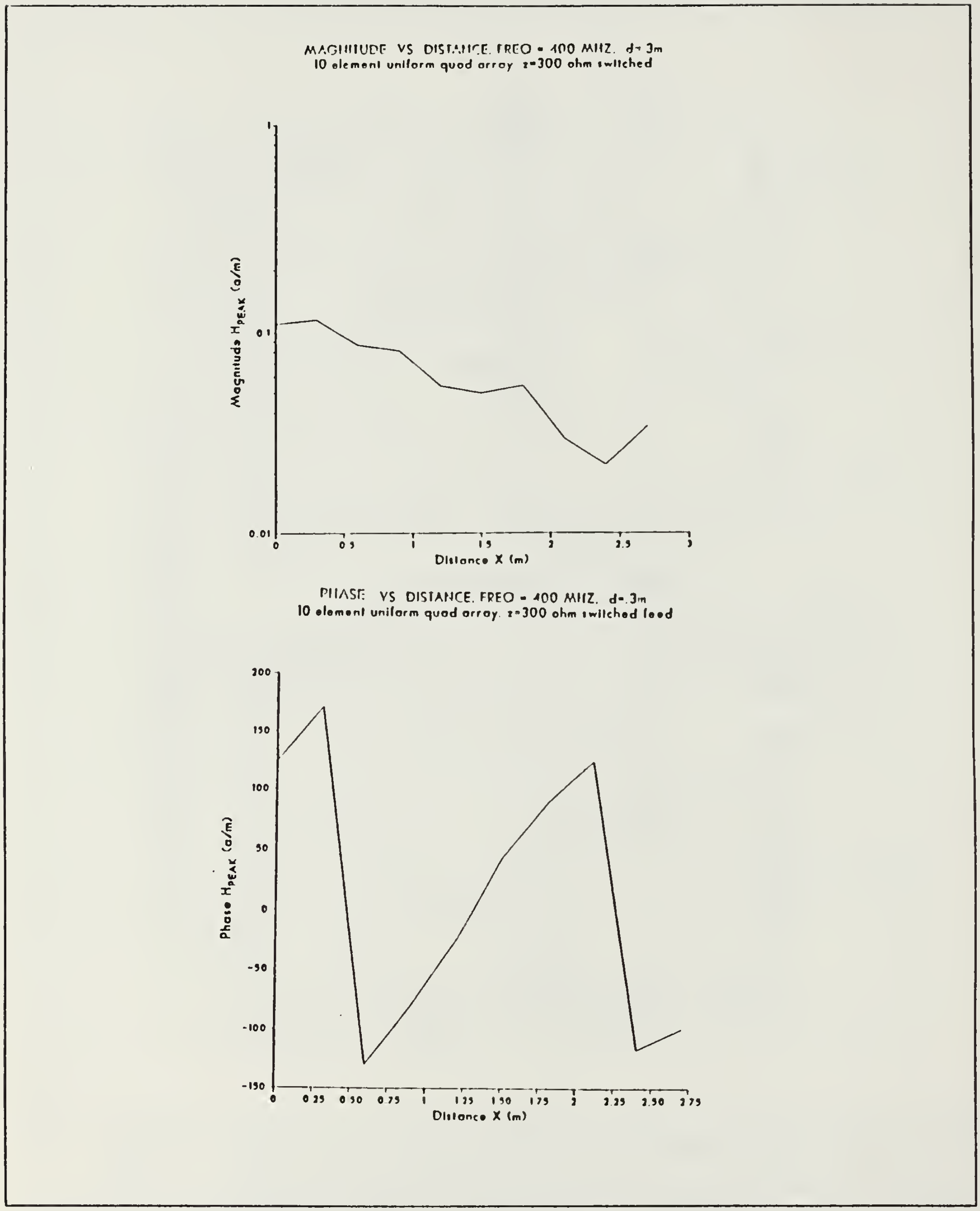


Figure 10. Current Amplitude and Phase in the Backward Radiation Region of a Quad Array

II. THE SELECTED APPROACH FOR INVESTIGATION OF THE QUAD LOG-PERIODIC ARRAY

A. SELECTED METHOD OF INVESTIGATION

The method of investigation was planned in two main steps. The first step was to provide more detailed information about the potential of the quad log-periodic antenna (QLPA). The method of investigating the near field properties of a uniformly periodic antenna was proposed by Mayes, Deschamp, and Patton and was chosen as a starting point. They suggested that the knowledge of the near-field properties of a uniformly periodic structure whose geometry is the counterpart of that of the log-periodic configuration, could be analyzed over a frequency range to identify the necessary characteristics for a successful log-periodic structure [Ref. 9]. In independent research projects, Tezmen and Johnsen utilized this approach to investigate the potential of small loop arrays and half square arrays as log-periodic antennas [Ref. 10, 7]. Following this approach, a quad uniformly periodic array (QUPA) could be analyzed to determine if a quad log-periodic structure could be successful.

For the uniformly periodic structure to be considered as having potential for development as a log-periodic antenna, the analysis should provide information, over the frequency range of interest, to demonstrate the following:

1. Supports backward radiation,
2. Creates sufficient current decay to eliminate the end effects,
3. Must not suffer large variations in electrical properties.

The identification of the characteristic properties indicates that, with proper scaling, a log-periodic quad antenna can be developed.

The second step was to design several computer models of a QLPA with different line characteristic impedances having different scaling and spacing factors. This was based on the results of the first step and was meant to compare the performance of the models in terms of antenna parameters, such as radiation patterns, half-power beamwidth, front-to-back ratio, and input impedance. Depending on the results, this would determine the most promising model. Next, the selected model was analyzed numerically using NEC to get data for both radiation patterns and near magnetic fields. Examination of the radiation patterns is the most effective way to observe the performance of log-periodic antennas. The purpose of calculating near magnetic field data in addition to radiation fields was to obtain the k-β diagrams of the QLPA by using near magnetic field data and observe the relationship between the radiation patterns and the k-β diagram. From k-β diagrams it is possible to identify the frequency regions where backward radiation occurs in uniformly periodic arrays; thus, it is possible to determine the potential of a candidate log-periodic structure. A uniformly periodic array is one in which all the elements, dimensions, and spacing between the elements are the same. For the log periodic case it is not easy to obtain the k-β diagram. The k-β diagram approach, used in the analysis of the uniformly periodic structures, is based on the analysis of infinite-length structures. Since practical structures are of finite length, their current distribution usually will be different than the infinite structures and some deviation in behavior may occur even in uniformly periodic structures. For example, the boundary lines between the various length regions are not sharply defined. Effective radiation may occur from a finite structure at frequencies where the phase constant lies within the slow-wave region [Ref. 11]. In the uniformly periodic case, d is constant while k is the controlled variable in obtaining the k-β diagram. For a log-periodic case, the period d, continually increases as one moves away from the feed with the frequency fixed. By fixing k and making d variable, the k-β diagram for the log-periodic structure may be obtained. With this approach, it is assumed that β on the log-periodic structure is determined only by local behavior of the structure [Ref. 12]. Also, since the log periodic structure is not uniform at a given frequency, different space harmonic phase constants are found for each cell along the structure. For these reasons, methods other than the k-β diagram technique are generally used in the analysis of log-periodic structures. One of the methods used in this thesis is the evaluation of amplitude and phase plots of element currents to determine regions which create backfire radiation and comparison of this information with radiation patterns and near magnetic fields. A single precision version of the Numerical Electromagnetics Code (NEC) was used throughout the simulation process, after comparing accuracy of double precision calculations.

B. APPLICATION OF THE K-B DIAGRAM

One of the characteristics of a log-periodic structure is that of backward radiation. It is possible to tell whether or not an array possesses the capacity for backward radiation by examining a k-β diagram, which is also called a dispersion or **Brillouin** diagram (Figure 11) [Ref. 8].

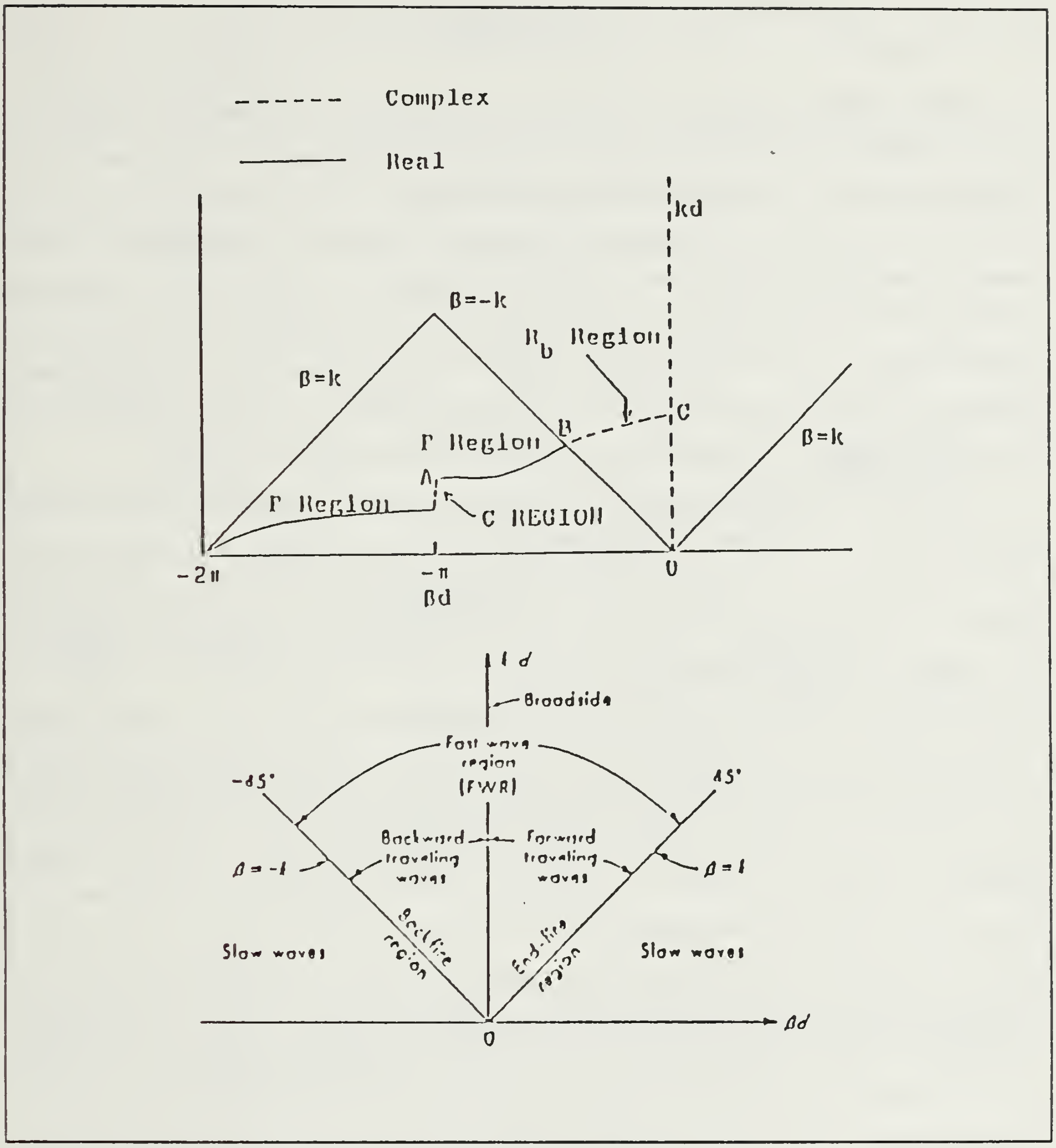


Figure 11. k-β Diagram and its Radiation Regions [Ref. 12]

This diagram is obtained by plotting the free space constant k versus the propagation constant β (or kd versus βd, where d is the antenna element spacing). It is only necessary to show one period since the log periodic antenna characteristics repeat every 2π. For free space propagation:

$$k = \beta = \frac{2\pi}{\lambda} \qquad (2.1)$$

The backward-travelling wave is created by coupling of the forward-travelling wave on the transmission line and the space harmonics of the elements. To achieve this desirable condition, the feeder wave medium must produce a fast wave along the structure to facilitate radiation. The determination of whether a wave is considered fast or slow is based on the relationship between the phase propagation constant of the wave on the structure, β, and the free space number, k. A slow wave is defined to exist when β is greater than k ($k < \beta$), or equivalently when the phase velocity of the feeder wave is travelling on the structure faster than the phase velocity of a wave radiating in free space. Conversely, a fast wave is generated when the condition $k > \beta$ exists.

According to Mittra and Jones the k-β diagram can be separated into three different regions [Ref. 12]. These are the propagation (P) region, the complex (C) region and the radiation (R) region. The propagation or P region corresponds to the feed excitation region in the antenna and has very little or no attenuation (normally found in the slow-wave areas). The complex or C region occurs at $\beta = \mp \pi$ (normally found in slow wave areas), and acts as a stopband filter where the attenuation is high but coupling to space is poor, therefore the complex region does not facilitate radiation. The C region will not be present in the k-β relationship for many structures, but will probably be present in structures that demonstrate large variations in electrical properties. The third region, radiation or R region, is where an antenna is an effective radiator. It is also located in the fast wave portion of the diagram, that is, where k is greater than β . The radiation region is normally subdivided into an R_f region, for forward radiation (away from the feed point), and an R_b region, for backward radiation (toward the feed). The most successful log-periodic antennas have radiation occuring in the R_b region near the line where β = -k. The R_b region should also have a large amount of attenuation to facilitate radiation into space. The direction of propagation for the waves radiated under these conditions is given by

$$\theta = \cos^{-1} \frac{\beta}{k}, \qquad (2.2)$$

where θ is measured from the axis of the structure [Ref. 11]. In Hudock's study of a uniform monopole array, he closely examined the relationship between the subdivisions of the R region and the far field propagation patterns as shown in Figure 12 [Ref. 11].

The transition from backward to forward radiation appears to occur gradually across the fast wave region with the most directional radiation patterns occuring close to the "fast-to-slow" boundary.

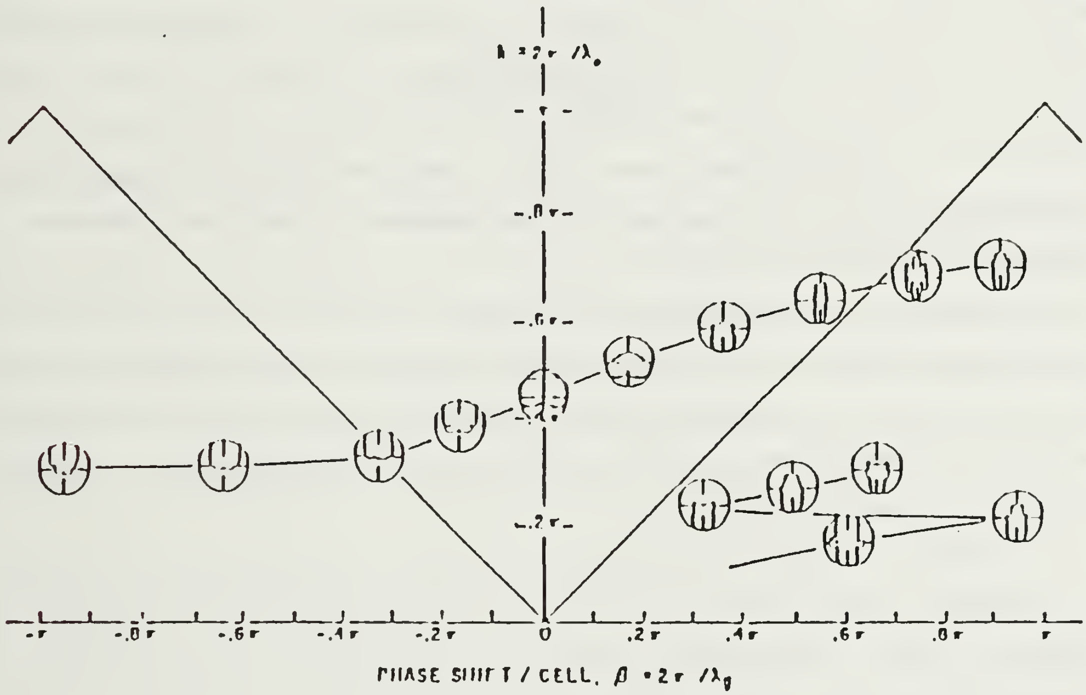


Figure 12. Hudock's Diagram Relating the k-β Relationship to Far Field Radiation Patterns [Ref. 11]

Thus, for this thesis, the importance of the k-β diagram comes from the fact that, in uniformly periodic arrays, it is possible to identify frequency regions where backward radiation occurs by examining the k-β diagram. Since backward radiation is an important characteristic of successful log-periodic antennas, the k-β diagram of its uniform counterpart is a very useful tool in determining the potential of a candidate log-periodic structure.

C. TECHNIQUE OF OBTAINING THE K-B RELATIONSHIPS

There are two methods for obtaining the k-β relationship for periodic structures. First, the theoretical approach, which involves developing a characteristic function in terms of β, is a very complex method and is developed in detail by Mittra [Ref. 13]. Second, the experimental approach investigates the near magnetic field properties of a periodic structure. Due to the complexity of the analytical approach proposed by Mittra, the experimental approach was selected for the investigation of the k-β properties of the QLPA. The experimental approach of investigating the near magnetic field characteristics has been previously employed on several structures and has proven to be a satisfactory method of obtaining the characteristics of a structure from which the phase relationship can be obtained.

To determine β, the amplitude and phase of the current along the transmission line must be deduced from the near field of the structure to determine the properties of the feeder wave. Since the magnetic near field is directly proportional to the current along the conducting elements, the relative current phase and amplitude can be determined from near field measurements.

Standing wave patterns will normally be observed for the current distribution along the transmission line of the structure in frequency regions far from resonance. The standing wave pattern indicates if the structure acts as a simple transmission line. Thus, measuring the distance (d) between the nulls or minimum points, it is possible to determine the guide wavelength, λ_g:

$$\lambda_g = 2d \tag{2.3}$$

Knowing λ_g, at non resonant frequencies, β can be calculated from the measurment.

$$\beta = \frac{2\pi}{\lambda_g} = \frac{\pi}{d} \tag{2.4}$$

As the frequency approaches resonance, the amplitude of the feed wave and current distribution attenuates as it travels down the structure (away from the feed point). Therefore, the magnitude of the reflected wave is very small and is not large enough to create an appreciable standing wave pattern. Consequently, the propagation constant β can no longer be determined by an observation of the standing wave pattern. Actually, the incident feeder wave is a travelling wave with a resultant progression of phase with distance. In this frequency range, β is now dependent on the change in phase, $\Delta\phi$, with respect to distance Δd, and is defined as the slope of the phase change with distance.

$$\beta = \frac{\Delta\phi}{\Delta d} \tag{2.5}$$

or

$$\beta = \frac{\Delta\phi}{\Delta d} = \frac{2\pi\Delta\phi}{360\Delta d} \tag{2.6}$$

The attenuation per cell in db is also provided from the amplitude plot.

In earlier experiments performed by Hudock and Tezmen the measurment of change of phase of the current with distance was based on the concept of comparison of a measured point to a reference point. For this experiment, the measurements were made in a manner similar to earlier experiments. Instead of constructing a prototype structure and using a laboratory setup to measure the near fields, the structure was modeled on a computer using the Numerical Electromagnetics Code (NEC). Experimental data was obtained from simulation runs with controlled parameter variations for observing the calculated response of the structure. Utilizing the capabilities of NEC, a near magnetic field investigation can be conducted on quad uniformly periodic arrays in which the amplitude and phase of the near magnetic fields are determined. The near field is usually considered to extend to 0.1λ. NEC requires that near field calculations be taken at a distance no closer than $10^{-3}\lambda$. Several runs were performed for magnetic field calculations at distances of $0.001\lambda - 0.01\lambda$. A comparison of these distances shows a magnitude difference of less than four percent and a phase difference of less than twelve percent. All NEC information used in the final analysis was for near fields at a distance of 0.0041λ at the resonant frequency because it was a convenient location for the geometry.

When NEC is programmed for the near magnetic field at one frequency, the output is complex with units of magnitude in amps per meter and phase in degrees. These values are given for the x, y, and z components for each antenna element. The x-directed magnetic fields were used for this analysis since the antenna array was placed in the Y-Z plane with the wave propagating in the x-direction. Using a plotting program, PLOTNF, the phase values were plotted for each type of antenna feed at several different frequencies and element spacings. The slope of each plot was then multiplied by the element spacing d and converted to radians to produce one point on the k-β diagram

($kd - \beta d$ diagram). The current magnitude output was used to derive α in the complex propagation equation:

$$\gamma = \alpha + j\beta \qquad (2.7)$$

These values were also plotted using PLOTNF. The ratio of maximum to minimum amplitude was converted to decibels per meter, divided by the distance over which it varied, and then multiplied by the antenna element spacing to produce one point on the attenuation diagram. The k-β and attenuation diagrams for QLPA are presented and discussed in the next chapters.

D. THE NUMERICAL ELECTROMAGNETICS CODE (NEC)

Quad log-periodic arrays used in this thesis were modeled on the IBM system 3033 main-frame computer by using the Numerical Electromagnetics Code (NEC), version three. NEC is a computer code designed to provide analysis of the electromagnetic response to metal structures. NEC was developed at the Lawrence Livermore Laboratory, Livermore, California, under the sponsorship of the Naval Ocean Systems Center, the US Army and the Air Force Weapons Laboratory.

It is a user-oriented computer code and was developed as an upgraded version of the Antenna Modeling Program (AMP) to obtain numerical solutions for integral equations which describe the current distribution on the structure [Ref. 9]. By employing the technique known as the method of moments, the code reduces integral equations of the form

$$\int I(Z')K(Z,Z')dZ' = -E^{i}(Z) \qquad (2.7)$$

to a system of simultaneous linear algebraic equations developed in terms of the unknown current components, I(Z′) [Ref. 3].

The NEC code provides accurate solutions to current distributions of a particular structure, and then utilizes the current values to evaluate structure impedances, radiation patterns, and near electric and magnetic fields.

The code can handle models with nonradiating networks and transmission lines connecting parts of the structure, imperfect or perfect conductors, and lumped element loading. Structures may also be modeled in free space or over a ground plane that may be either a perfect or imperfect conductor.

Structures may be excited either by voltage sources on the structure or by an incident plane wave which may be linearly or elliptically polarized. NEC outputs may include currents and charges, radiated fields, and near electric or magnetic fields. For more accurate calculations, double precision versions are also available to the user. The NEC code installed on the Naval Postgraduate School mainframe employs single and double precision versions of the code.

III. NUMERICAL PROCEDURES

A. DEVELOPMENT OF THE COMPUTER MODEL

Since the method selected to analyze performance was based on the experimental evaluation of the uniform array, the size of the array structure had to be established both in terms of element lengths and element spacings. The utilization of NEC removes laboratory restrictions on construction size of the antenna; therefore, the major consideration in selection of a computer model is the tradeoff between antenna performance and deployment capability. As the number of the elements in the array increases, the performance of the antenna also increases, but construction of the antenna will require more time, space, and manpower (in case of mobile arrays), which are crucial factors under battle conditions. A computer model must be chosen which is operationally practical. A midrange frequency of 300 MHz was selected as it represents the midpoint frequency for NAVY VHF/UHF devices. Uniform spacing between elements was selected arbitarily to be one tenth of a resonant wavelength. The selection of spacing was arbitary since it is a function of the input frequency; consequently, changing the frequency at the input is the same as varying the element spacing for fixed frequency. The radius of the wire was chosen as 0.000814 meters which is number 14 gauge wire.

The use of a 10 element array was an arbitary selection. It was chosen to make the array at least one wavelength long for the selected resonant frequency, and, it saved computational time over longer arrays.

Another variable was the characteristic impedance of the transmission line "feeder" connecting the elements. The initial value used was 300 ohms and other measurements were made above and below this value. Three different types of voltage feeds were also modeled in NEC for comparison and will be discussed in the next section.

In the investigation of the quad uniformly periodic array, the characteristic impedance of the transmission line "feeder" connecting the elements, the spacing between the elements, and the type of voltage feed were all systematically varied. The values of characteristic impedance studied were 50, 180, 300, 500, and 700 ohms. The spacing distance was 0.05 m, 0.1 m, 0.15 m, 0.2 m, 0.25 m, and 0.3 m.

A set of near magnetic field data was collected for the following conditions as shown in Figure 13 :

1. Switched parallel voltage feed,

2. Unswitched parallel voltage feed,
3. Staggered or "improved" voltage feed.

The near magnetic field was calculated in the z-direction at 0.129884 meters, approximately 0.0041λ above the center of each element. As mentioned in the previous chapter on the k-β diagram, the plotted values for each frequency determined one point on the k-β diagram and the attenuation diagram. Other sets of k-β and attenuation diagrams were formed by changing the distance between the elements in the array.

The next major step was to design a successful quad log-periodic array. At the start of the design the only parameter available was the range of frequencies where backward radiation had occured on k-β diagrams of a uniformly periodic array. Considering that the length of the array should be around one wavelength long at the lowest frequency, then the distance from the apex to the longest element should vary in accordance with the selection of the lowest frequency.

By examining the k-β diagrams, it was possible to choose a characteristic impedance of 300 ohms and a spacing of 0.25 m and 0.3 m to start the design. From both diagrams, the mid frequency of backward radiation was observed as 340 MHz. Five elements were chosen to complete the total backward radiation frequency range. The values of τ, σ, d_n, and α for the distance spacing, $d_{upa} = 0.3$ m, of the uniformly periodic array were found:

1. $\tau_{avg} = 0.914$,
2. $d_n = 0.2107$,
3. $\sigma = 0.119$,
4. $d_{n-i} = \dfrac{.4214\tau}{1+\tau}$; i= ...,-1,0,1,2,...,
5. $\alpha = 5.3$ degrees

Similarly for the distance spacing, $d_{upa} = .25$ m, of the uniformly periodic array, they were found to be:

1. $\tau_{avg} = 0.915$,
2. $d_n = 0.2206$,
3. $\sigma = 0.125$,
4. $d_{n-i} = \dfrac{.4412\tau}{1+\tau}$; i= ...,-1,0,1,2,...,
5. $\alpha = 5.4$ degrees

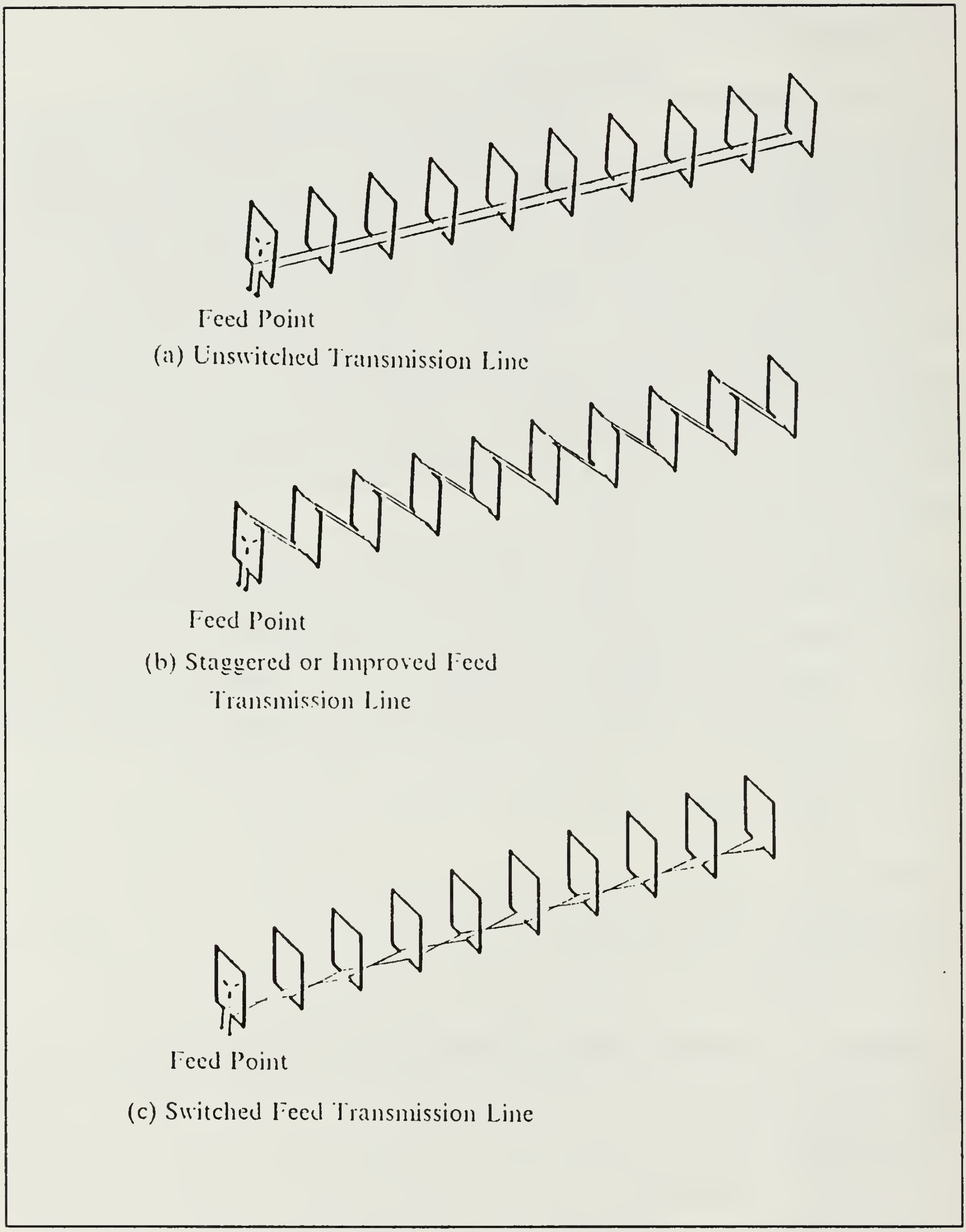


Figure 13. Types of Voltage Feeds

Only the switched transmission lines were tested because their k-β diagrams were the most promising.

Since there is not a well established methodology for the analysis of log-periodic antennas, the analysis of the performance is "experimental". In this respect, radiation patterns are one of the key parameters for evaluating the performance of log-periodic structures. First, the radiation patterns were calculated for the uniformly periodic arrays over frequencies identified as being in the radiation region of the k-β diagrams for the above three types of transmission line voltage feeds. Secondly, for the log-periodic structure, radiation patterns were calculated in free space at the resonant and also non-resonant frequencies with the switched transmission line, using NEC. Verification of the results were made from the input impedance of the QLPA (Smith Chart plot) and also from the amplitude and phase distribution of the element currents of the QLPA.

IV. EXPERIMENTAL RESULTS

As mentioned in the previous chapter a plotting program, PLOTNF, was used to assist in the analysis of the near field data. By plotting the magnitude and phase relationships of the near magnetic field, characteristic regions could be identified and the propagation constant, β, could be determined. The propagation constant, β, was calculated for various frequencies from the numerical values provided by NEC using relationships defined by Mittra [Ref. 13] and utilized by Hudock, Tezmen, and Johnsen [Ref. 11, 10, 7]. Along with the calculation of β, the attenuation of the field over the structure was calculated by the normalized ratio of the magnitude values. The calculated data for β and attenution were then plotted on a Brillouin diagram to obtain the structure's properties and its potential for development as a log-periodic antenna.

A. QUAD UNIFORMLY PERIODIC LOOP ARRAY

The uniformly periodic structure consists of an array of ten identical loops whose circumference is one meter. In analyzing the data from the near field plots presented in Appendix B for three types of feedlines for quad loop arrays, the following responses were observed:

1. UNSWITCHED TRANSMISSION LINE

For the element spacing distance of 0.05 m through 0.3 m, similar responses were observed for the different values of characteristic impedance of the transmission line. No backward radiation occured for any of the cases. An example is shown in Figure 14. Only forward radiation occurred, and one or more standing waves were present.

Thus, the uniformly periodic array with an unswitched transmission line is an ineffective radiator. Therefore the structure with this type of transmission line does not have the potential to become a successful log-periodic antenna.

2. IMPROVED (STAGGERED) FEED TRANSMISSION LINE

The near magnetic field investigation continued with the analysis of the quad uniform array with an improved feed. This feed was investigated by Baron [Ref. 2], who found that it provides more uniform properties than the basic QLP antenna and was suggested for further investigation.

1. For a spacing distance of 0.1 m, the k-β diagrams, a sample of which is shown in Figure 15, demonstrate that the backward radiation regions are very narrow and the attenuation is not high enough (at least 3 dB per cell) to provide effective radiation. There are also ranges of frequency for which a clear situation can not be

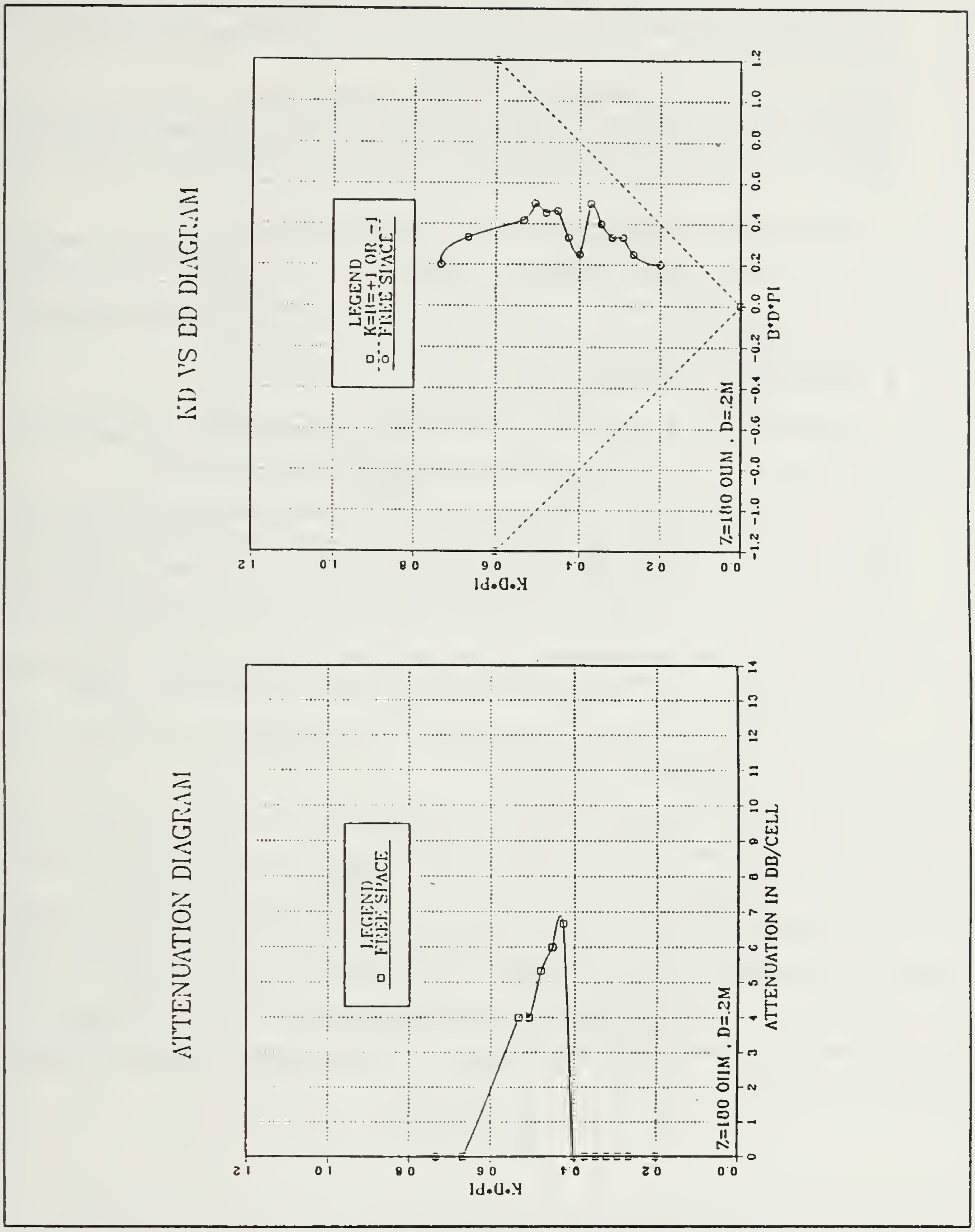


Figure 14. k-β and Attenuation Diagrams of Unswitched Feed Transmission Line, $Z_0 = 180$ ohms

identified, due to the fact that the phase of the current switches back and forth. These regions are named "messy" regions on the k-β diagrams; for example, the case of $Z_0 = 500$ ohms shown in Figure 16.

2. For element spacing distances of 0.2 m, 0.25 m, and 0.3 m, the backward radiation regions are more broadband, but the attenuation is lower in these regions in comparison to the attenuation of the forward radiation. Similarly, as stated before, there are also "messy" regions present.

The near field investigation of the quad uniformly periodic array with staggered feed shows the array supports backward radiation, but the attenuation is not high enough (at least 3 dB per cell) to show potential for the structure as a successful log-periodic antenna and thus does not warrant further investigation.

3. SWITCHED TRANSMISSION LINE

The analysis of k-β diagrams (Appendix A) of the switched transmission line showed different results from the two previous types of transmission lines.

1. For an element spacing of 0.2 m there are narrow and broadband backward radiation regions. This is the case when characteristic impedances are 50, 180, and 300 ohms. In the case when transmission line characteristic impedance is 500 ohms, there is a broadband backward radiation region where attenuation is low (less than 3 dB per cell), so the structure does not show potential as a log-periodic array.
2. For spacings of 0.15 m and 0.3 m similar responses were observed for the backward radiation regions, but the attenuation in these regions are higher than 3 dB.

The k-β diagrams for a transmission line of characteristic impedance $Z_0 = 300$ ohms are shown in Figures 17 through 20.

The k-β and attenuation diagrams for a spacing of 0.3 m are in Figures 17 and 18, identifing a backward radiation region in the frequency range of 250 to 425 MHz, while the attenuation has values from 1.8 dB to 6 dB. For a spacing of 0.25 m, Figures 19 and 20, graphically depict a propagation region followed by a backward radiation region at a frequency of 250 to 475 MHz. The attenuation is between values of 0.5 dB to 5 dB. Thus, the near field characteristics demonstrated by the switched transmission line structure show potential for the structure as a log-periodic antenna and warrant further investigation.

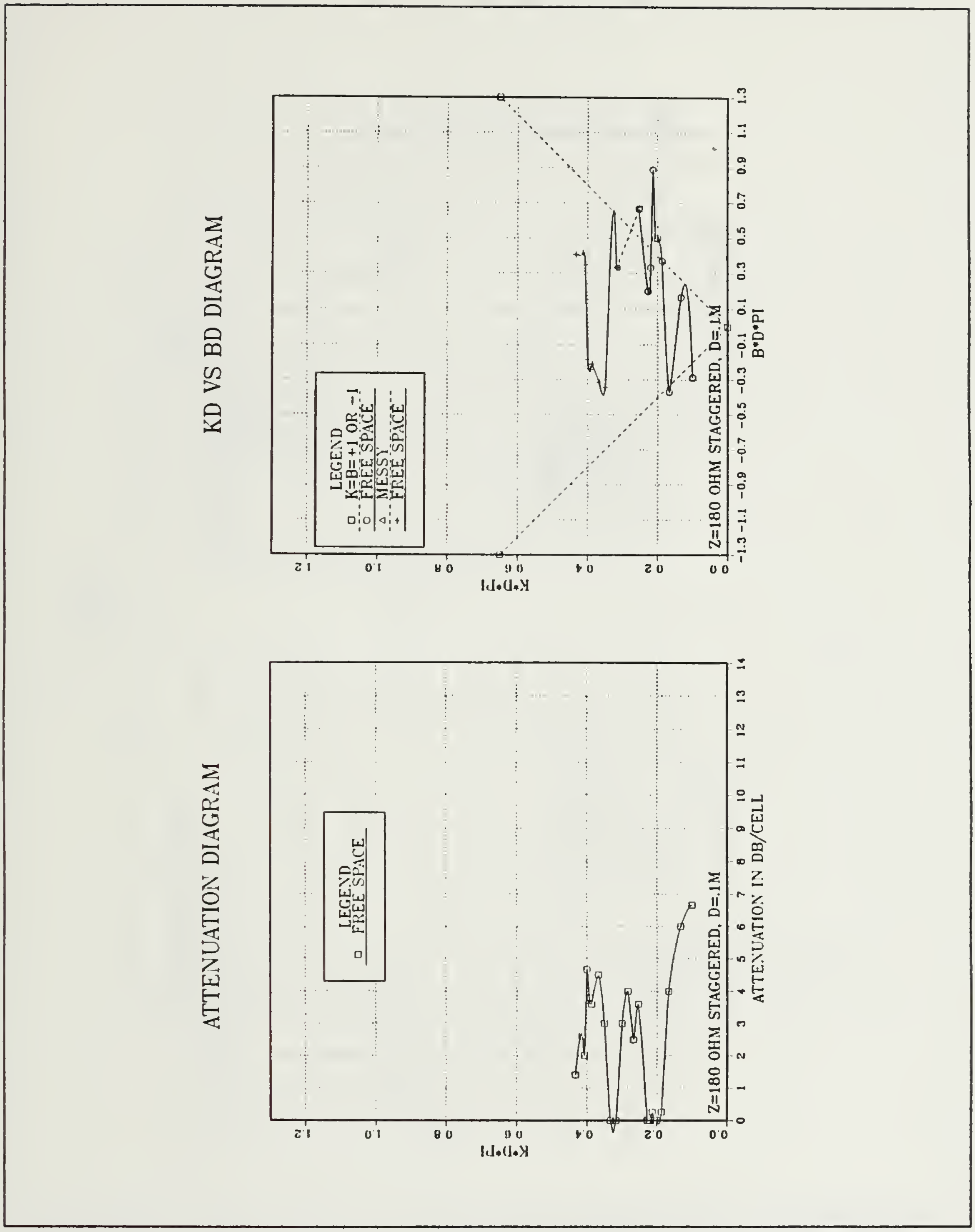


Figure 15. k-β and Attenuation Diagrams of Staggered Feed Transmission Line, $Z_0 = 180$ ohms

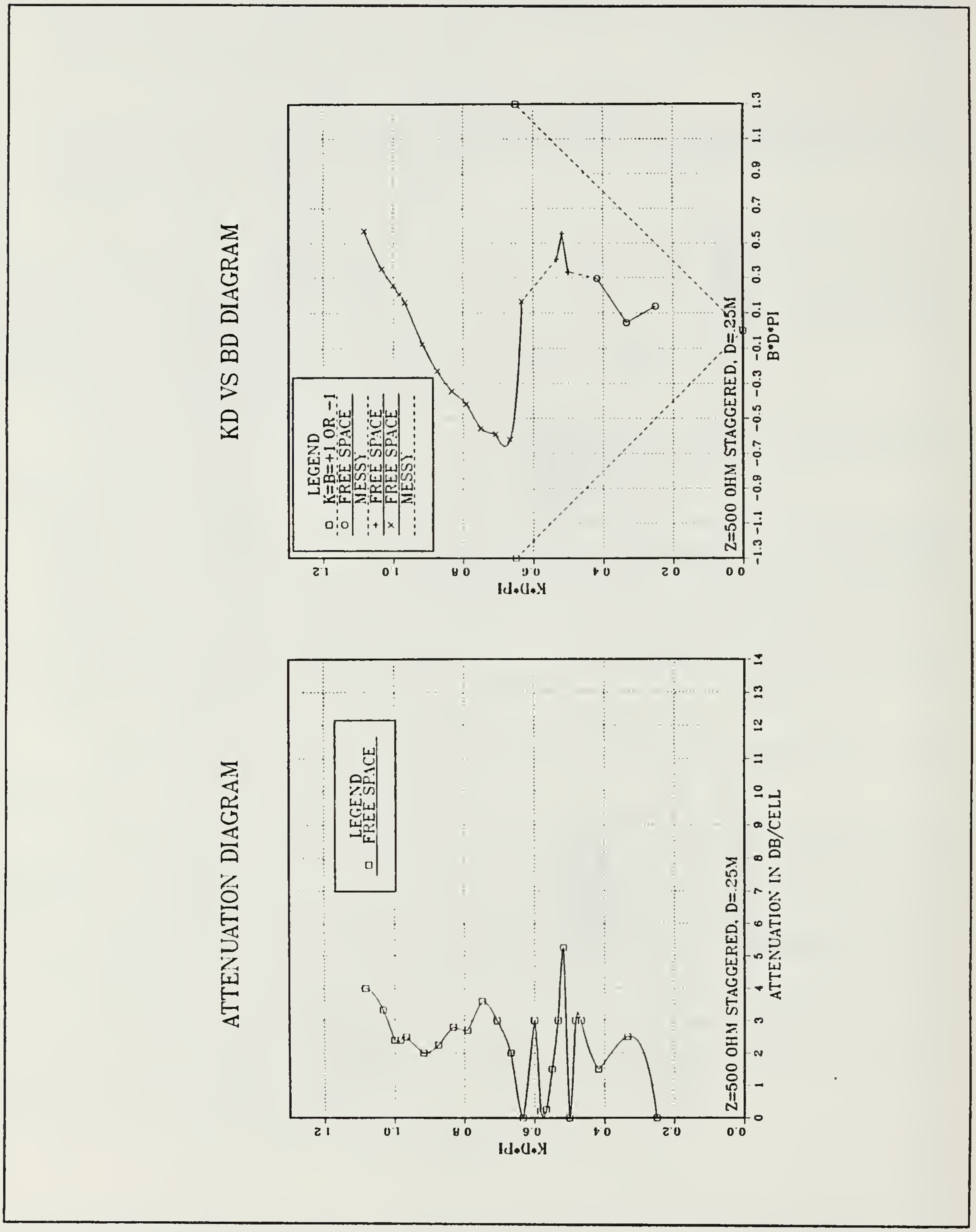


Figure 16. k-β and Attenuation Diagrams of Staggered Feed Transmission Line, $Z_0 = 500$ ohms

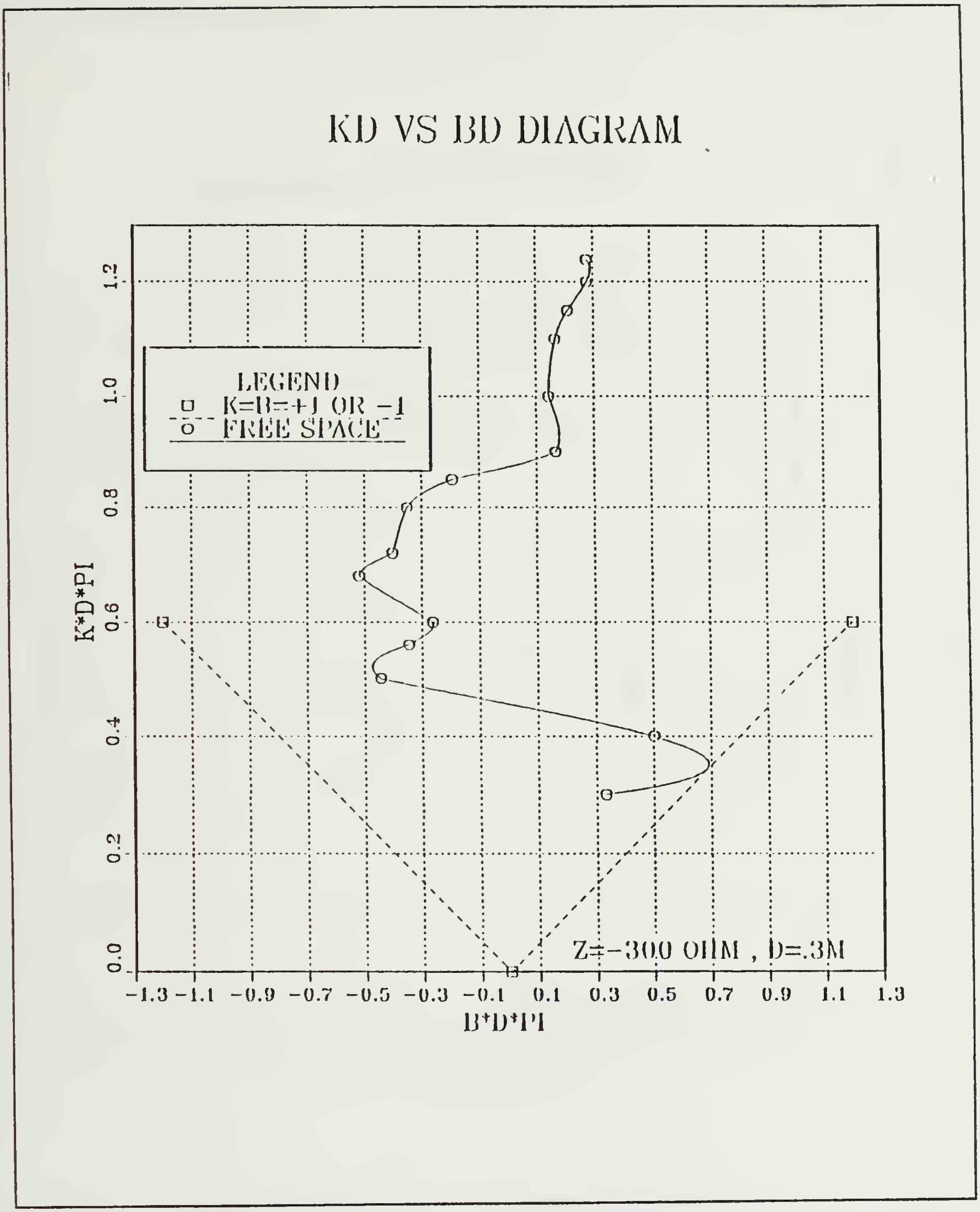


Figure 17. k-β Relationship of QUPA with Element Spacing Distance d = 0.3 m

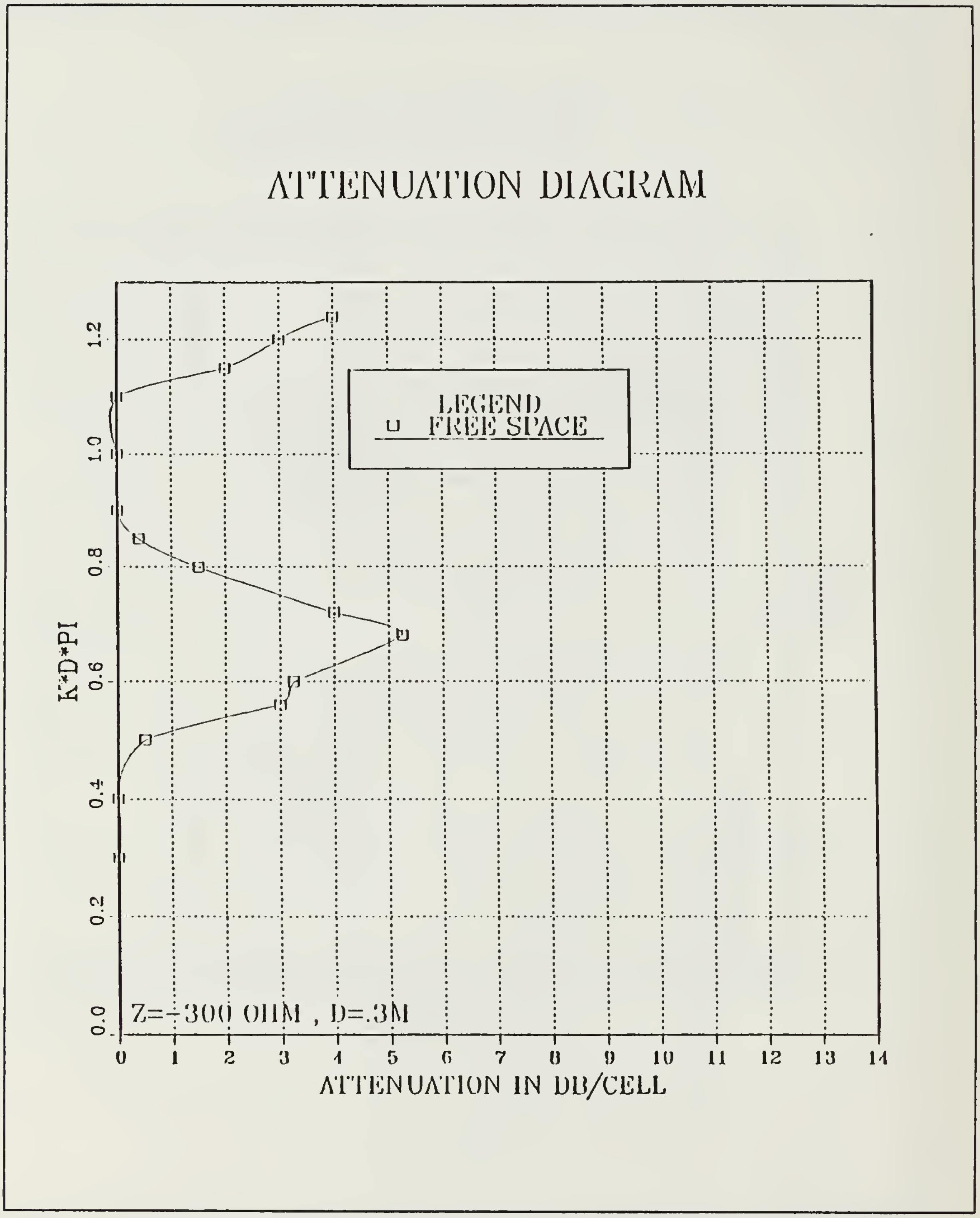


Figure 18. The Observed Attenuation of the QUPA with Element Spacing Distance d = 0.3 m

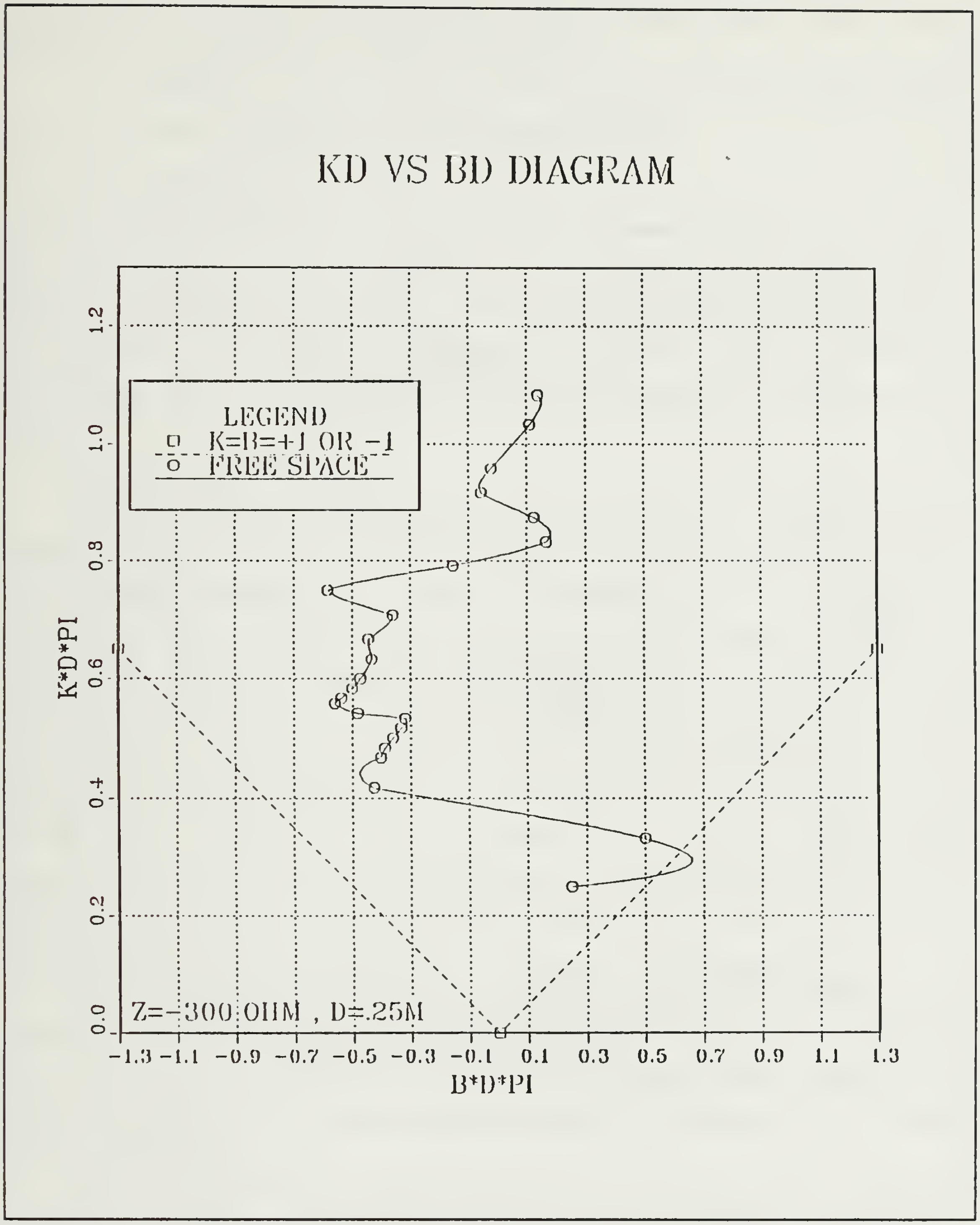


Figure 19. k-β Relationship of QUPA with Element Spacing Distance d = 0.25 m

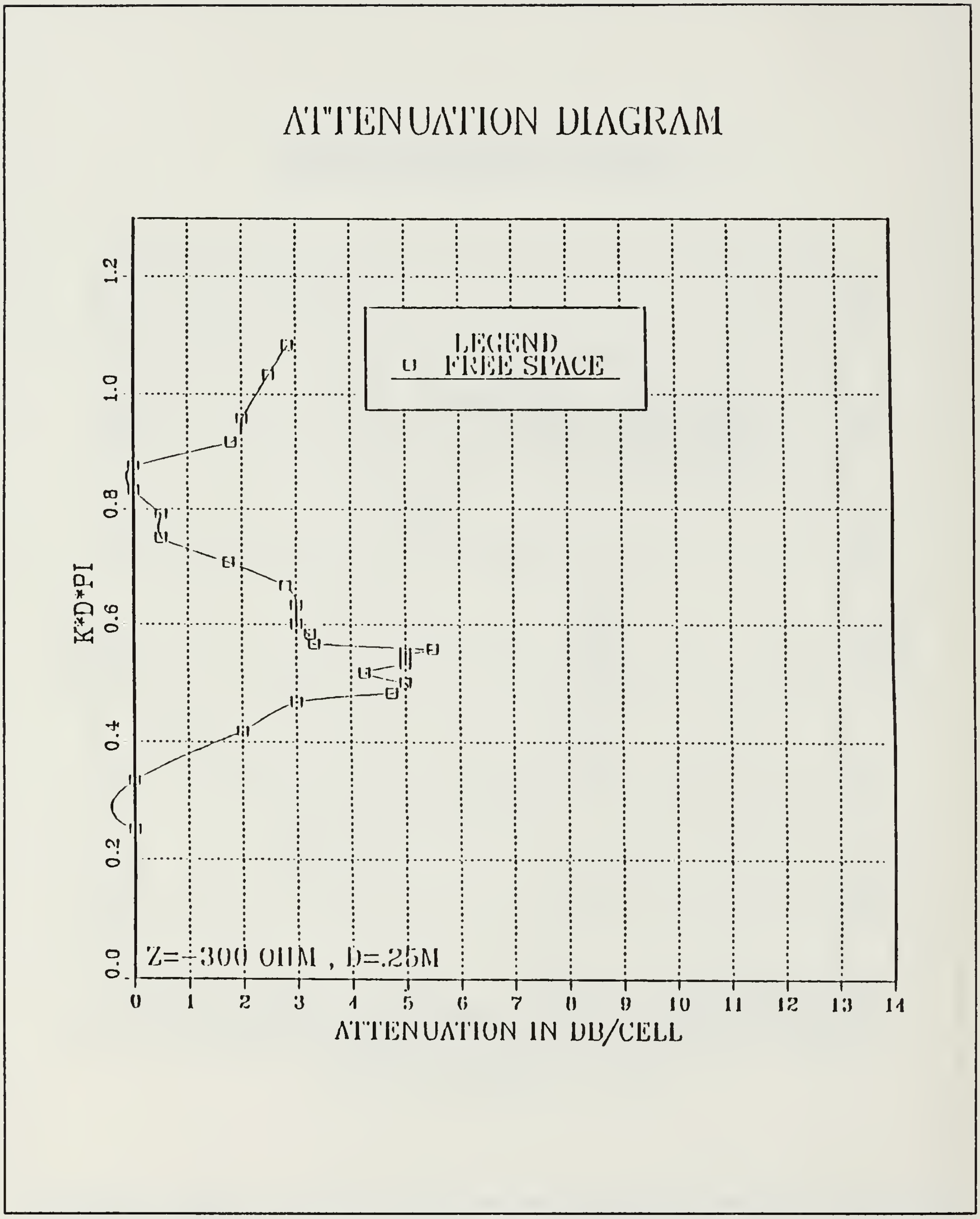


Figure 20. The Observed Attenuation of the QUPA with Element Spacing Distance d = 0.25 m

In Appendix C, the far field radiation patterns of a QUPA with a switched feed transmission line are shown as a function of frequency.

In Appendix H, the data files which are the inputs to the NEC program for the QUPA are presented.

B. QUAD LOG-PERIODIC ARRAY

The models shown in Figure 21 were run with a switched transmission line in free space. (Switching is the transposition of the transmission line between adjacent elements to generate a 180 degree phase reversal). The data collected included radiation patterns, input impedance, and magnitude and phase plots of structure element currents. The corresponding data files which were inputs to the NEC program are represented in Appendix I.

1. RADIATION PATTERNS

Free space radiation patterns showed the expected backfire radiation, directed toward the point of excitation, a trait which appears to be inherent in most of the successful unidirectional log-periodic antennas. It is believed to be the result of a space wave traveling along the structure in a direction opposite to the phase progression of currents in the feed line. The backward traveling wave is due to the existence of backward space harmonics in the spectrum of the periodic structure. The periodic structure should be such as to produce only waves which are quite slow at the frequencies where radiation is not intended. At frequencies where radiation is intended, one or more of the space-harmonic waves should be "fast" or "almost fast". Thus, for the log periodic structure, a feeder wave propagates toward the active (radiating) region under slow wave conditions. According to this theory, the dominant harmonic in the active region propagates in the backward direction [Ref. 11].

The responses of both of QLPA's designs were very similar, as expected, since the design parameters differed only slightly (Appendix E). The scaling and spacing factors were $\tau = 0.915$ and 0.914 and $\sigma = 0.125$ and 0.119 respectively. Increasing the number of elements in the log periodic array increased the performance of the array as shown in Appendix D.

Between 200-240 MHz and 560-590 MHz the front-to-back ratio is lower than for the rest of the frequencies although the main radiation is backfire radiation. The major reason for this is "truncation effects". If the structure were of the infinite type, the properties would repeat periodically and there would not be any performance variation. Near the low-frequency cutoff of 199 MHz, a sizable reflection of the fundamental wave

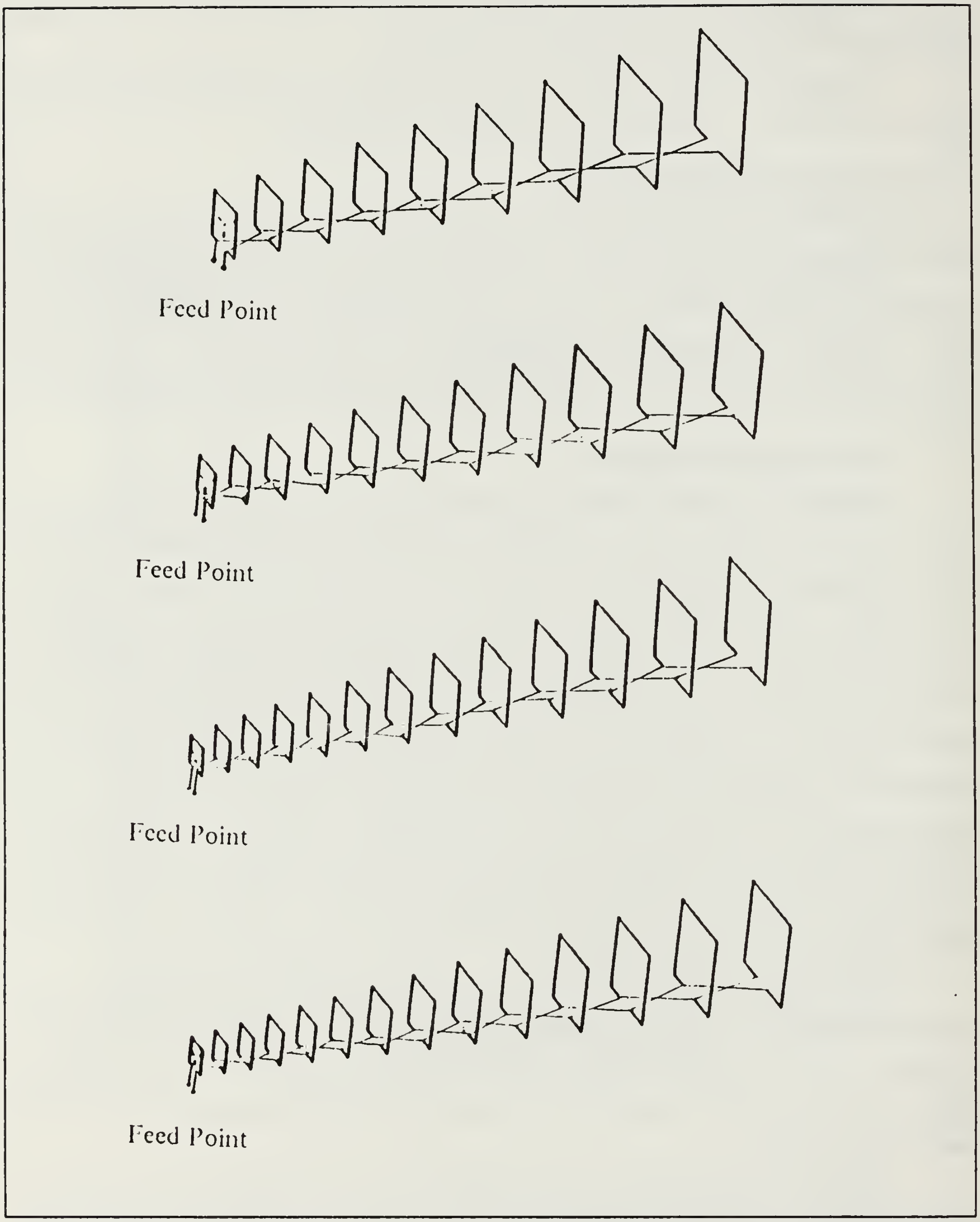


Figure 21. QLPA Models

(end effect) is produced by rear truncation. This reflected wave then travels back along the structure in the opposite direction, passing through the active region a second time where it is partially radiated. The resulting radiation pattern from this second pass is a reduced mirror image of the main pattern from the first pass [Ref. 14]. As frequency is increased, the electrical properties of the truncated structure converge to characteristic values. The 13 element QLPA has a low frequency limit of 240 MHz. Above this frequency the antenna displays fairly small radiation. Figure 22 shows a sample radiation pattern in free space. Appendices D and E include other radiation patterns calculated in free space. Patterns show an average half power beamwidth of 56 degrees and an average gain of 5.3 dBi at resonant frequencies. In Tables 1 through 4 the antenna parameters, power gain, half power beamwidth, and input impedance are shown versus frequency in free space.

2. AMPLITUDE AND PHASE DISTRIBUTION OF ELEMENT CURRENTS

Appendix F shows amplitude and phase plots of element currents for the 13 element QLPA ($\tau = .915$, $\sigma = .125$) in free space for various frequencies. These plots clearly show the possibility of obtaining a leading phase shift along some portion of the structure that will produce backfire radiation. On the plots, the left-most point corresponds to the smallest element which is one-wavelength in circumference at the upper cut-off frequency, 580 MHz. The feed line is connected to the array at this element. The right-most point corresponds to the longest element which is one wavelength in circumference at the lower cut-off frequency of 199 MHz. From the amplitude and phase plots of element currents, it can be observed that currents are strongest on resonant elements and on a few elements in front of the element which is near one-wavelength at the operating frequency. For elements, which form the active region of the array, the phase shift along the structure shows a leading phase condition. This corresponds to a backward traveling wave and leads to directivity which is predominantly backfire. Following the element which is closest to resonance, the current amplitude falls off suddenly showing a desired "end effect". As the operating frequency is increased or decreased the active region moves along the array but radiation patterns vary only slightly.

3. INPUT IMPEDANCE

Appendix H shows the input impedance of the structure plotted on Smith charts using the GRAPS plotting program. The VSWR is excellent. It is less than 2:1 throughout the frequency range. On the plots it is also easy to observe the end or truncation effect (straight line) which occurs at the lowest cut-off frequency of 200 MHz for the 13 element QLPA.

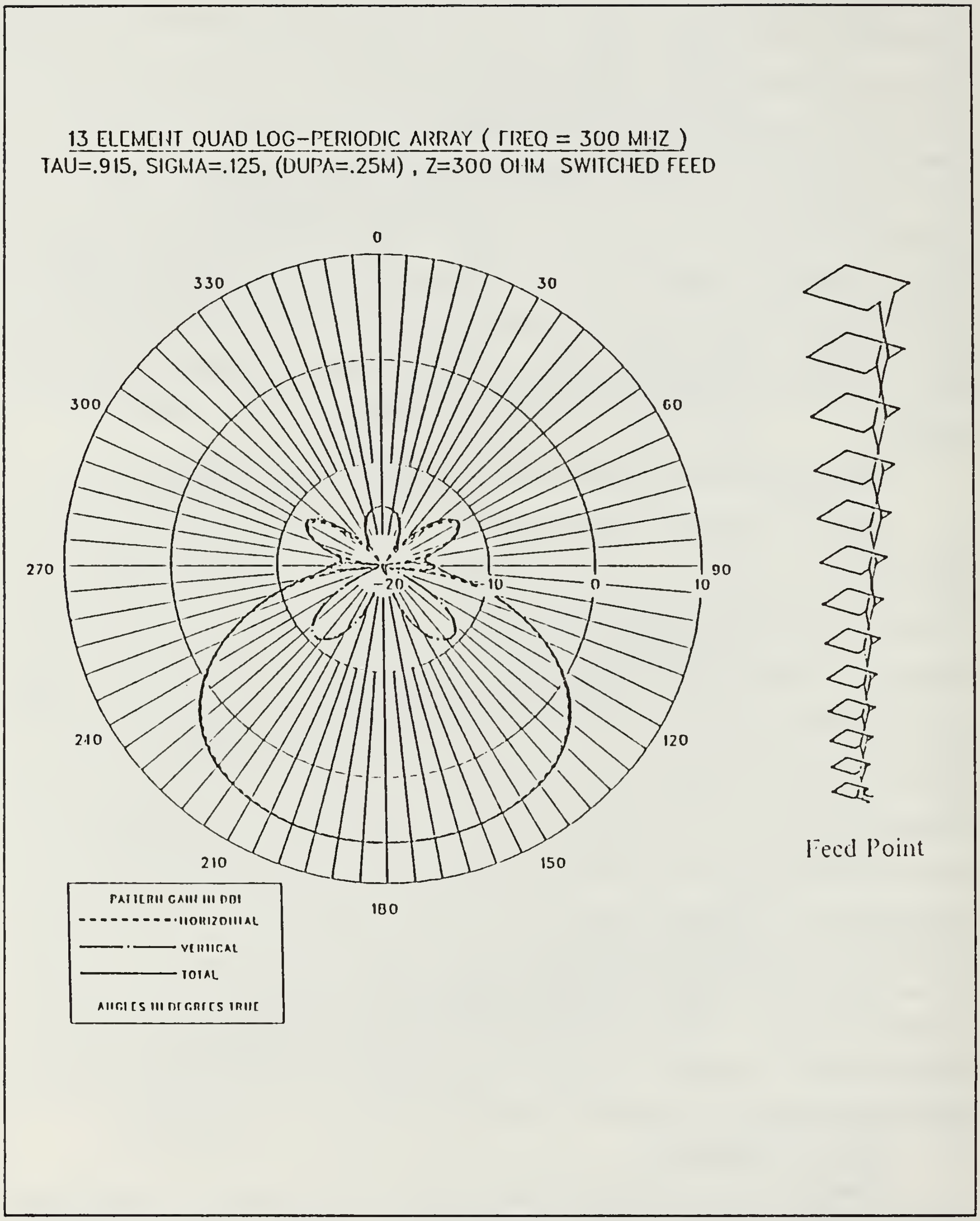


Figure 22. Horizontal Pattern at 300 MHz

Table 1. PERFORMANCE DATA FOR A 9 ELEMENT QLPA (TAU = .915, SIGMA = .125, Z = 300 OHM)

NUMERICAL RESULT IN FREE SPACE .				
Element	Frequency (MHz)	HPBW (degrees)	Gain (db)	Input Impedance
1	484.9	74	- 0.35	234.04 - j 97.93
2	443.7	67	2.29	221.95 - j 06.92
3	406.1	69	1.71	208.35 - j 69.77
4	371.6	60	3.96	232.16 - j 17.04
5	340	54	5.27	258.72 - j 27.14
6	311.1	47	6.00	258.72 - j 27.14
7	284.1	50	5.44	331.04 - j 65.16
8	259.9	39	7.49	309.46 + j 30.90
9	237.84	35	7.06	191.29 - j 37.79

Table 2. PERFORMANCE DATA FOR A 13 ELEMENT QLPA (TAU = .915, SIGMA = .125, Z = 300 OHM)

NUMERICAL RESULT IN FREE SPACE				
Element	Frequency (MHz)	HPBW (degrees)	Gain (db)	Input Impedance
1	579.2	76	- 1.25	243.28 - j 88.35
2	530.0	72	1.72	214.26 + j 5.41
3	484.9	66	1.48	205.75 - j 69.17
4	443.7	60	4.22	230.92 - j 21.27
5	406.1	58	4.72	255.19 - j 85.48
6	371.6	49	5.84	256.14 - j 25.37
7	340	49	5.69	332.08 + j 19.90
8	311.1	55	5.40	320.50 - j 28.82
9	284.1	50	5.87	262.25 + j 33.25
10	259.9	48	6.03	290.46 + j 53.46
11	237.84	61	2.85	315.87 + j 154.52
12	217.62	39	7.54	397.15 + j 117.28
13	199.12	35	7.41	436.75 - j 1.37

Table 3. PERFORMANCE DATA FOR A 9 ELEMENT QLPA (TAU = .914, SIGMA = .119, Z=300 OHM)

NUMERICAL RESULT IN FREE SPACE				
Element	Frequency (MHz)	HPBW (degrees)	Gain (db)	Input Impedance
1	487.2	76	- 1.08	252.06 - j 89.36
2	445.3	66	2.58	213.62 + j 04.96
3	407.0	70	1.56	215.22 - j 72.10
4	371.9	61	3.97	233.08 - j 15.62
5	340	54	5.26	254.36 - j 88.29
6	310.4	48	5.95	259.56 - j 23.43
7	283.7	50	5.00	327.61 + j 66.32
8	259.3	39	7.45	301.17 - j 29.95
9	237.0	36	7.07	202.11 + j 48.23

Table 4. PERFORMANCE DATA FOR A 13 ELEMENT QLPA (TAU = .914, SIGMA = .119, Z = 300 OHM)

NUMERICAL RESULT IN FREE SPACE				
Element	Frequency (MHz)	HPBW (degrees)	Gain (db)	Input Impedance
1	583.2	76	- 1.33	243.53 - j 91.83
2	533.04	70	1.72	215.76 + j 5.32
3	487.2	69	1.54	206.97 - j 70.00
4	445.3	41	4.27	232.01 - j 20.74
5	407.0	56	4.73	258.64 - j 86.32
6	371.9	49	5.80	255.45 - j 24.03
7	340	50	5.52	329.32 + j 26.714
8	310.4	55	5.36	327.62 - j 24.37
9	283.7	49	5.90	265.10 - j 0.20
10	259.3	48	5.91	287.97 + j 53.86
11	237.0	40	3.32	307.72 + j 160.53
12	216.6	40	7.46	397.75 + j 132.75
13	198.0	35	7.35	485.12 + j 26.60

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The purpose of this research was to investigate a uniformly periodic square loop (QUAD) array antenna with various feeds in order to establish optimum scaling and spacing factors, and then design a quad-log periodic array. The experimental objective of this research was accomplished, using the Numerical Electromagnetics Code (NEC). A near field investigation verified the presence of backward radiation regions which were suggested from k-β diagrams of successful log-periodic designs. This research also observed end or truncation effects of the structure.

From the experimental data, k-β diagrams were constructed for unswitched, switched, and staggered feed transmission lines. The k-β diagrams identified broadband backward radiation regions for switched transmission lines. That was also verified from the radiation patterns of the QLPA. Then, obtaining the optimum scaling factors τ and σ , computer models of quad log-periodic arrays were executed and provided data for radiation patterns, input impedances, and amplitude and phase plots of the element currents.

The models were run in free space with different combinations of switched transmission lines (transmission line impedances of 180 and 300 ohms, different scaling and spacing factors of $\sigma = 0.125$ and 0.119, $\tau = 0.915$ and 0.914, and various numbers of elements 9, 11, 13, and 14). Radiation patterns, input impedance plots, and magnitude and phase plots of the element currents were used to evaluate the performance of the antenna. Since there is not a well-established method of analyzing log-periodic arrays, examination of the radiation patterns was the major tool for determination of the performance of the array. The results can be listed as follows:

1. The QLPA with a switched feed transmission line shows characteristics of a successful log-periodic structure. The structure shows a unidirectional "backfire" radiation pattern with radiation being directed towards the small end of the array.

2. The structure exhibits nearly the same performance over the entire 200-500 MHz range. Between 200 to 240 MHz, there is performance degradation because of the truncation effect. As the frequency increases, performance of the antenna is stabilized and variations are less.

3. The VSWR is less than 2:1 throughout the entire frequency range.

4. With these design parameters the array exhibits an average gain of 5.3 dBi and an average half power beamwidth (HPBW) of 56 degrees.

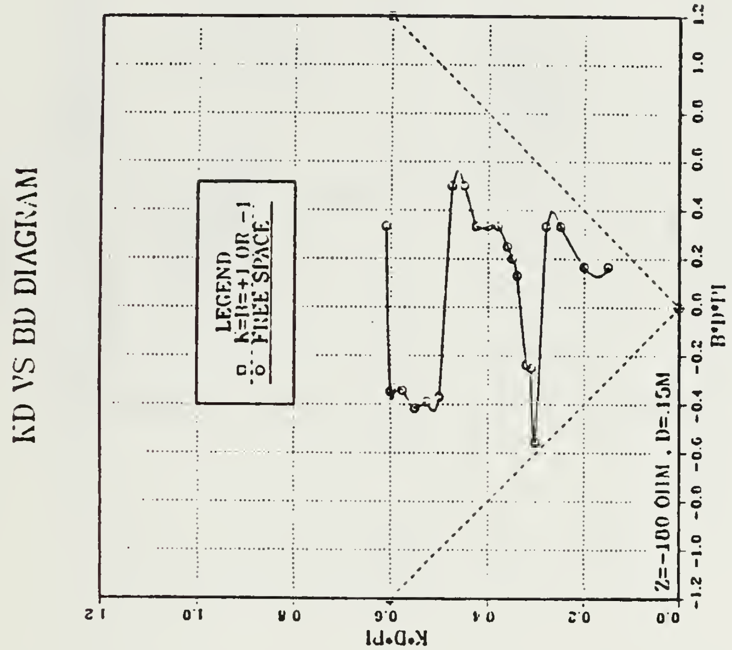
5. It should be possible to get a more directive radiation pattern and higher gain from the structure using a higher scale factor, but this in turn would require more elements to cover the frequency range.

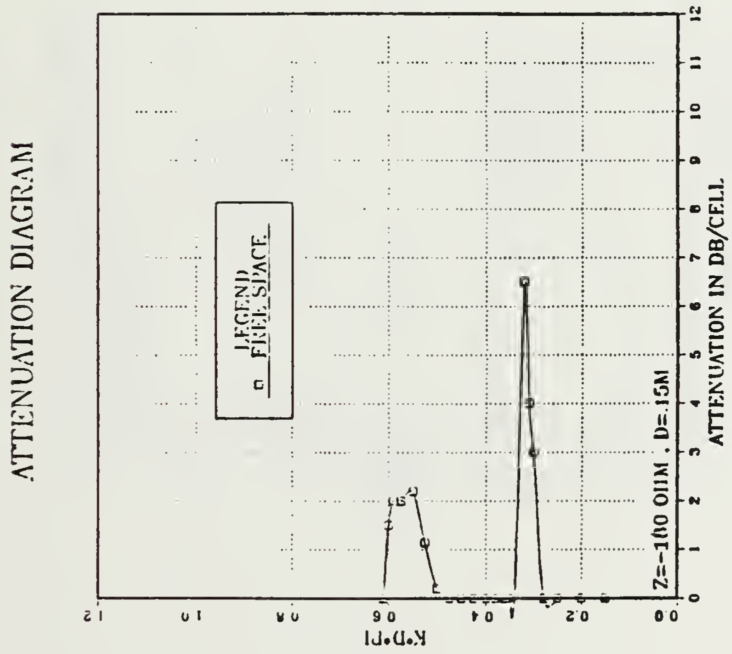
B. RECOMMENDATIONS

Based on the results of the study the following recommendations are made:

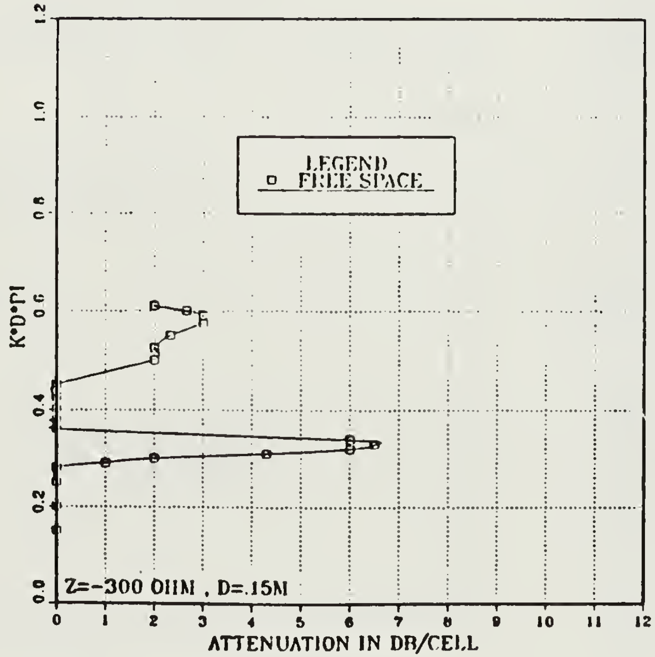
1. Although the results of the QLPA show satisfactory performance in free space, a study of the array should be done over perfect and lossy ground to see what additional effects occur under these kinds of conditions for HF frequencies (2-30 MHz).
2. Higher values of scaling and spacing should yield higher performance.
3. Using different scaling and spacing factors, it is possible to create an experimental set of design curves for the QLPA similar to those of the LPDA (Carrel's curves).
4. This thesis investigated near magnetic fields of uniformly periodic quad arrays and obtained k-β diagrams. From the k-β diagrams, frequency regions showing backward radiation were identified. In the absence of a well-established theoretical approach for log-periodic antenna design, the method used in this combined study and first suggested by Mayes, Deschamps, and Patton [ref. 11] has proven to be very successful and less time consuming than cut-and-try method. It is therefore recommended that before attacking log-periodic structures directly, a near magnetic field investigation of the uniformly periodic counterparts may give insight into log-periodic performance. Analysis of k-β diagrams of uniformly periodic structures can provide clues to the performance of log-periodic counterparts. If the study of uniformly periodic structures proves fruitful, it is highly probable that log-periodic counterparts will give good broadband performance. Near field analysis of uniformly periodic counterparts of many successful and unsuccessful structures shows this to be the case.

APPENDIX A. K-B DIAGRAMS AND ATTENUATION DIAGRAMS FOR A SWITCHED TRANSMISSION LINE

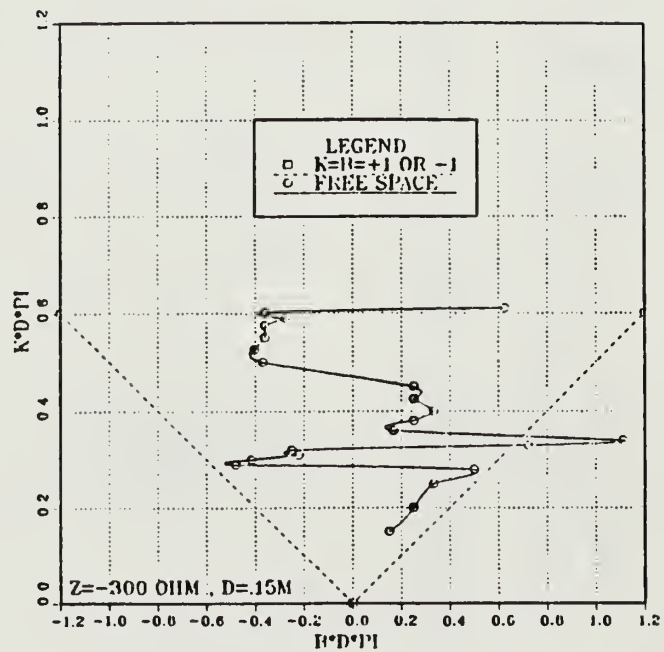




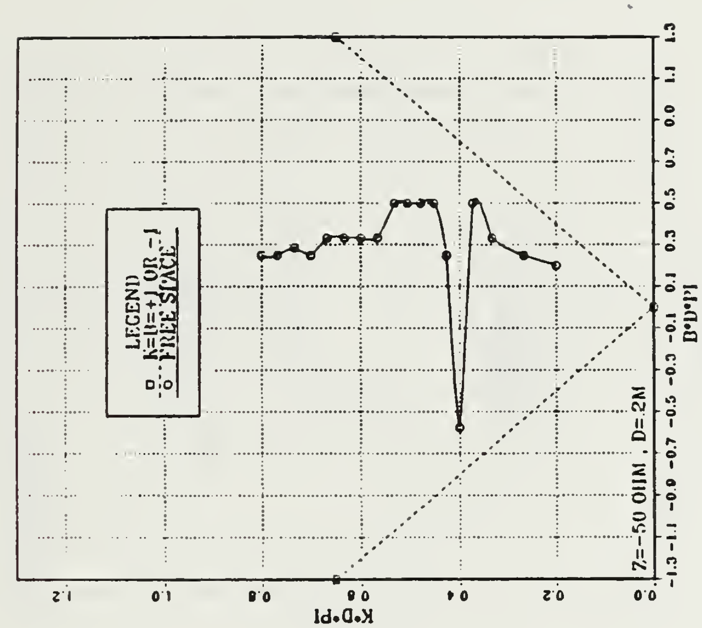
ATTENUATION DIAGRAM



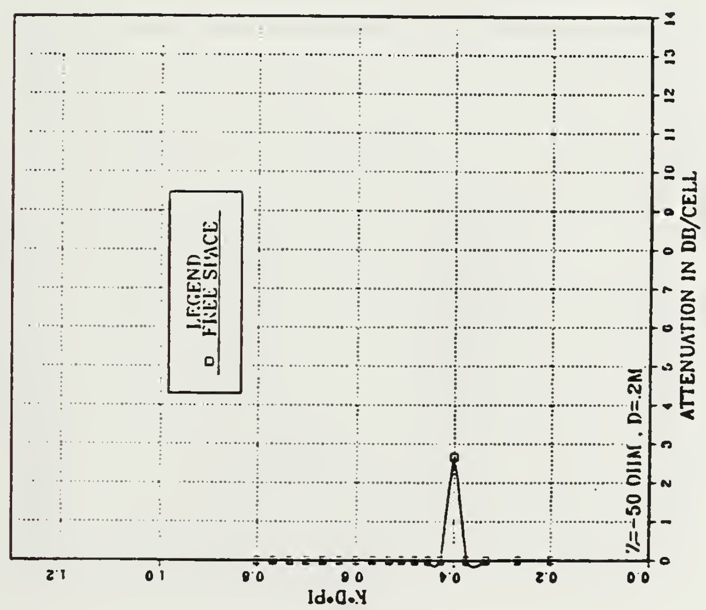
KD VS BD DIAGRAM



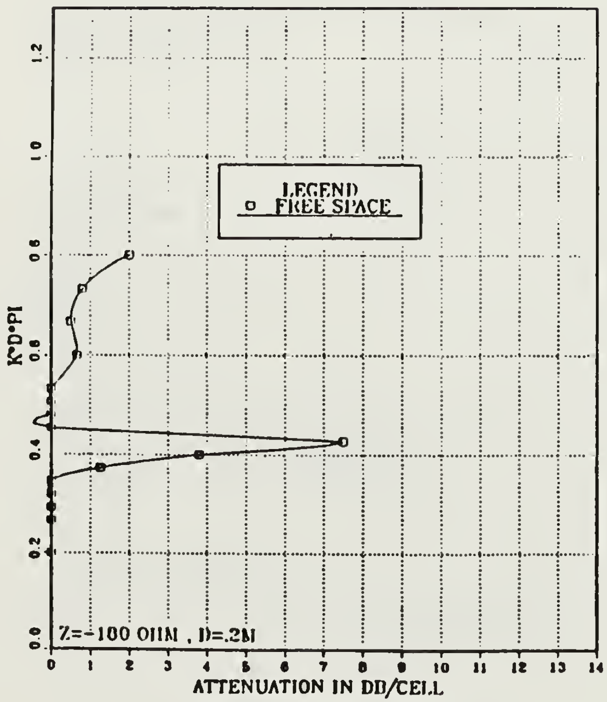
KD VS BD DIAGRAM



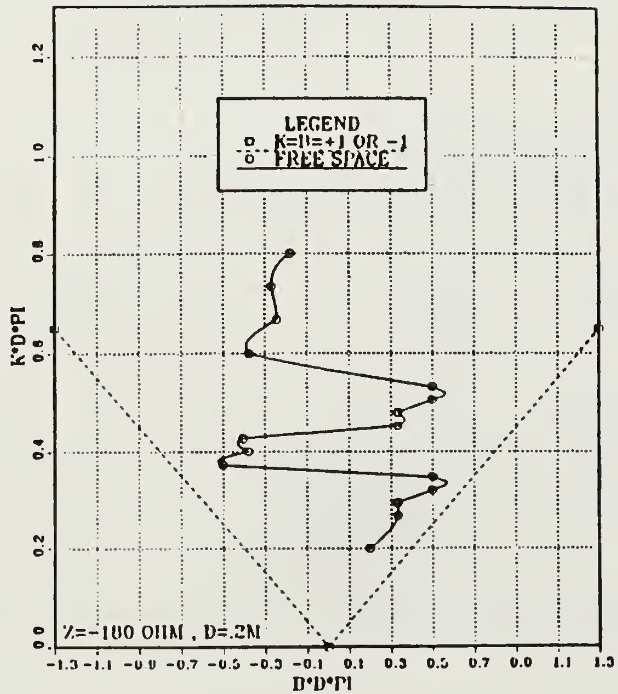
ATTENUATION DIAGRAM



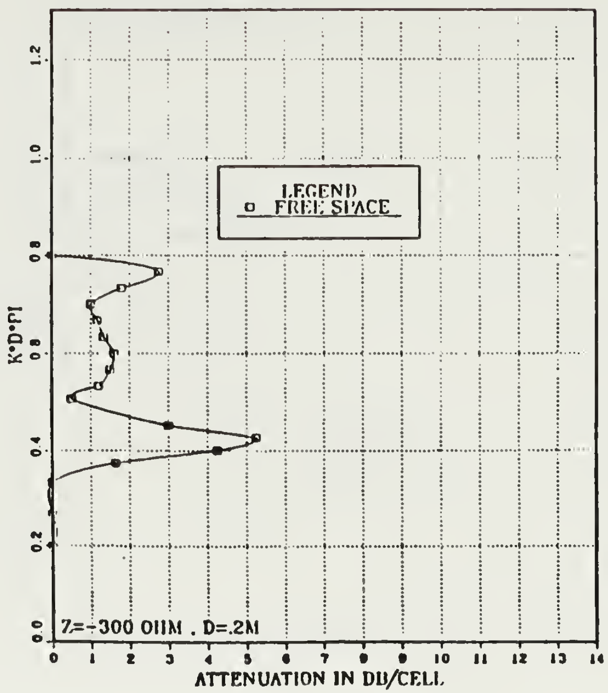
ATTENUATION DIAGRAM



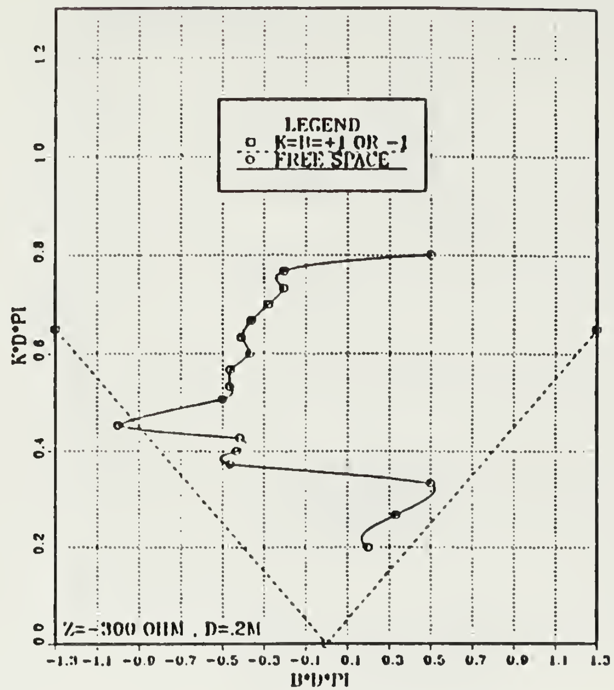
KD VS BD DIAGRAM



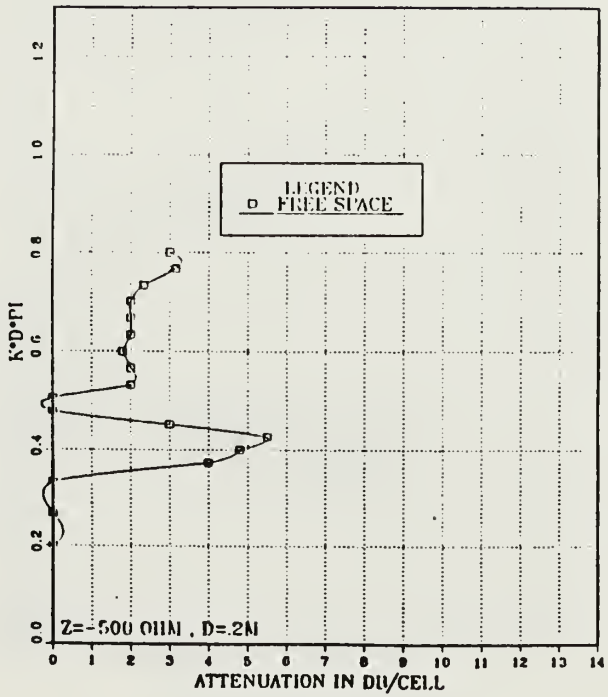
ATTENUATION DIAGRAM



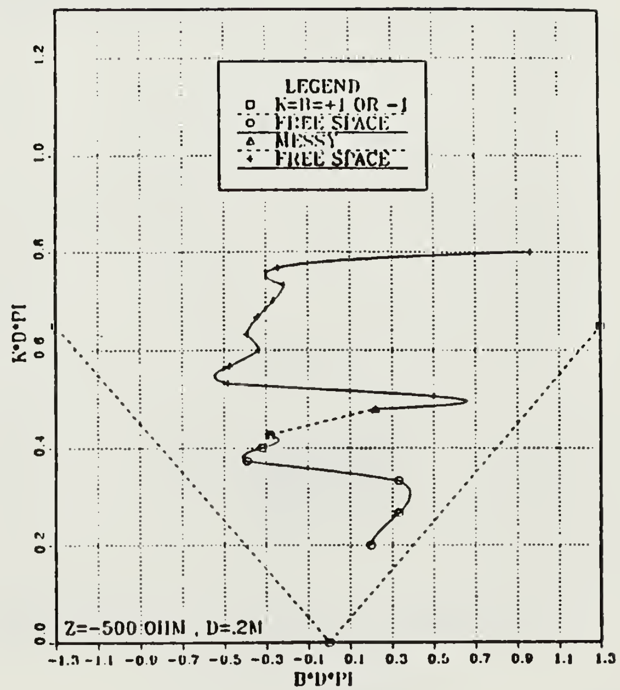
KD VS BD DIAGRAM



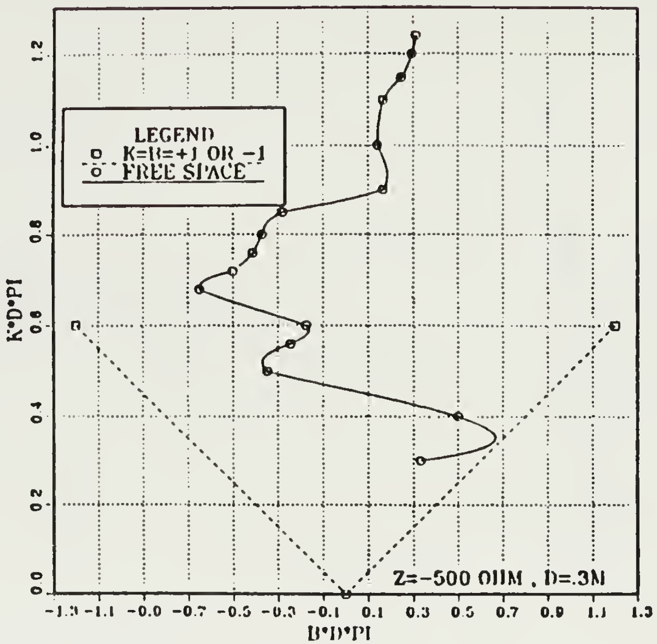
ATTENUATION DIAGRAM



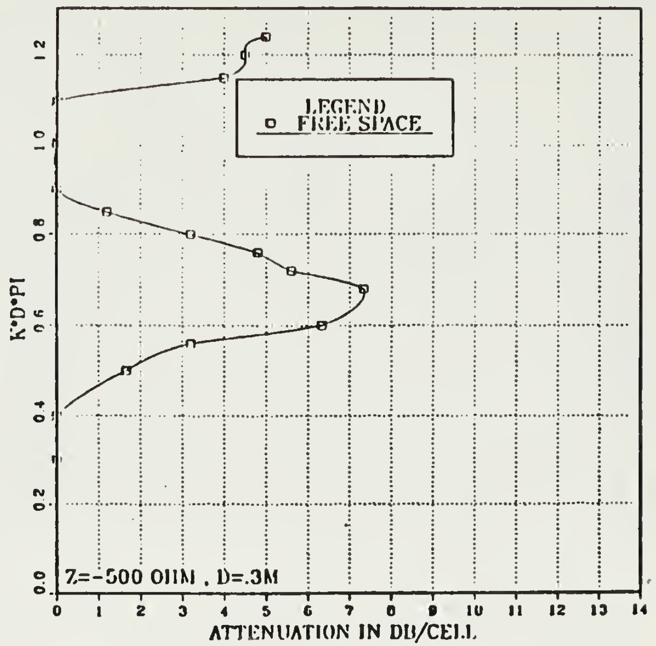
KD VS BD DIAGRAM



KD VS BD DIAGRAM

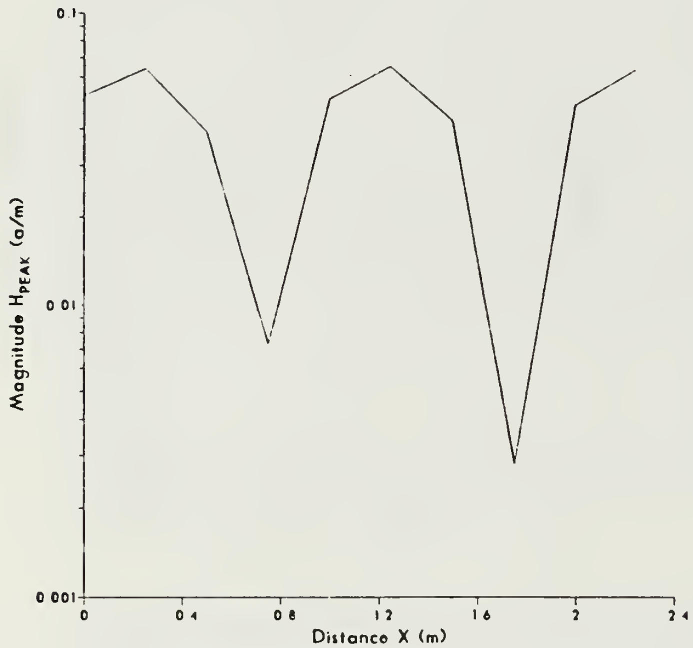


ATTENUATION DIAGRAM

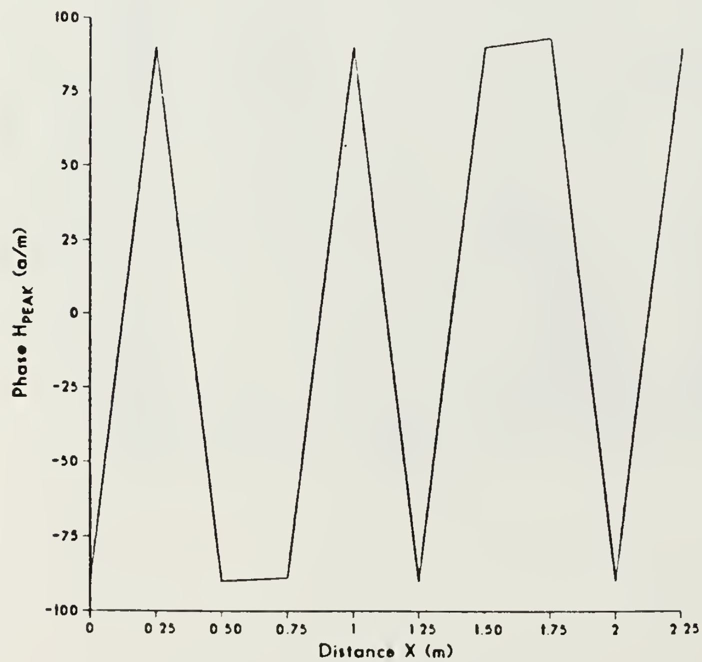


APPENDIX B. NEAR MAGNETIC FIELD EXPERIMENTAL RESULTS FOR A QUPA IN FREE SPACE

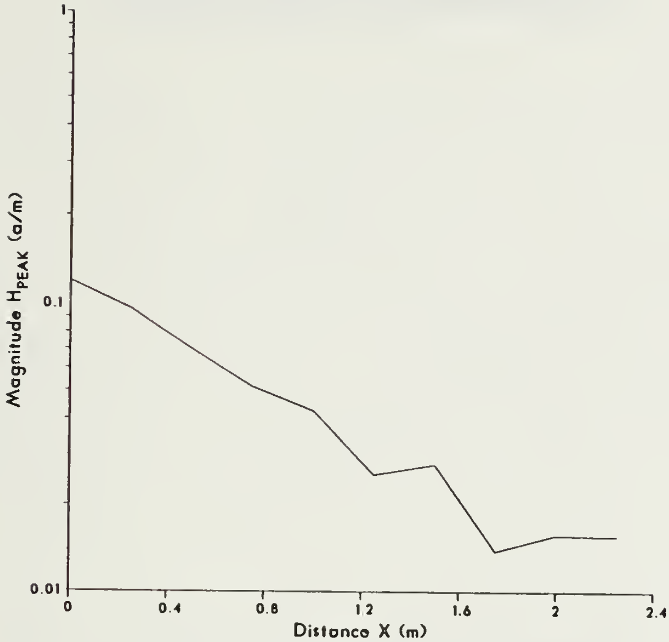
MAGNITUDE VS DISTANCE FREQ = 150 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched



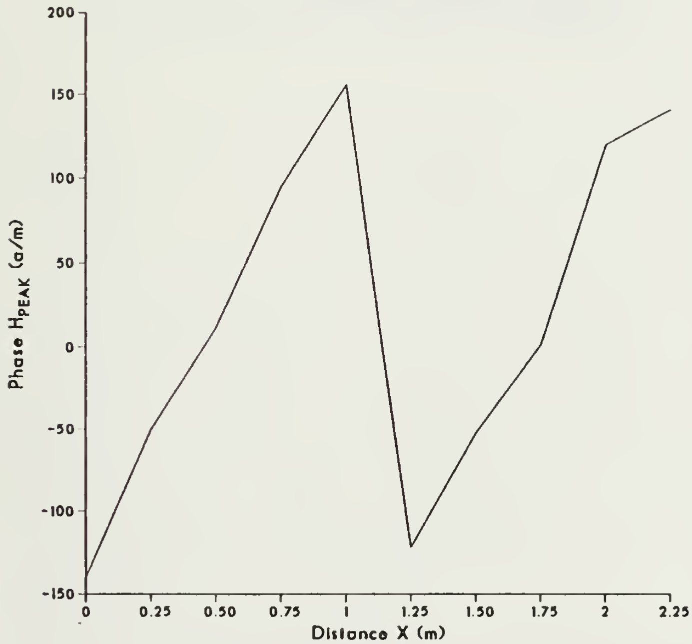
PHASE VS DISTANCE. FREQ = 150 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched feed



MAGNITUDE VS DISTANCE. FREQ = 280 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched

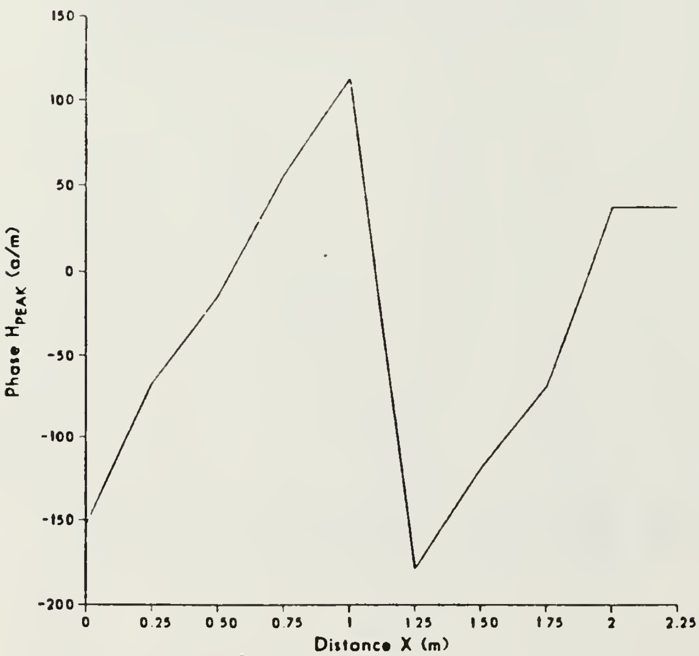


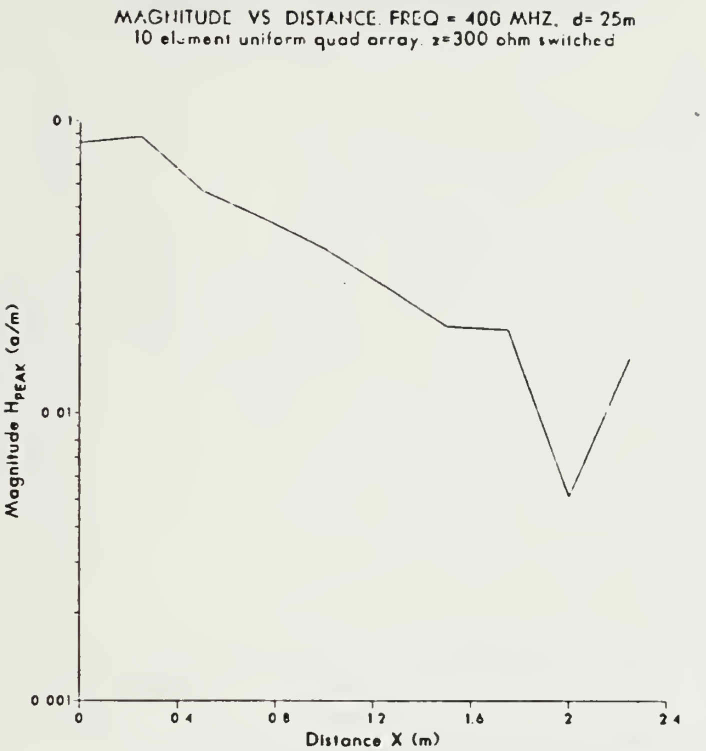
PHASE VS DISTANCE. FREQ = 280 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched feed

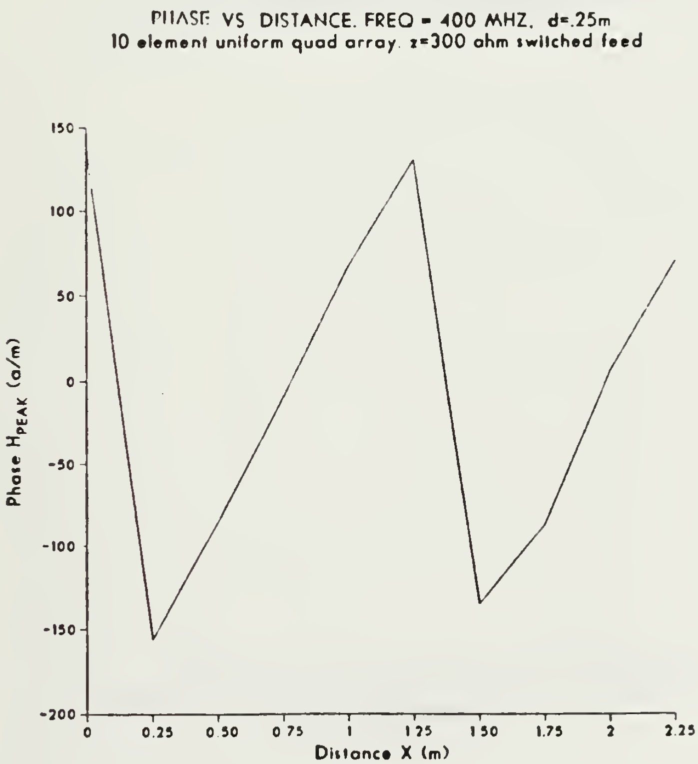


MAGNITUDE VS DISTANCE. FREQ = 300 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched

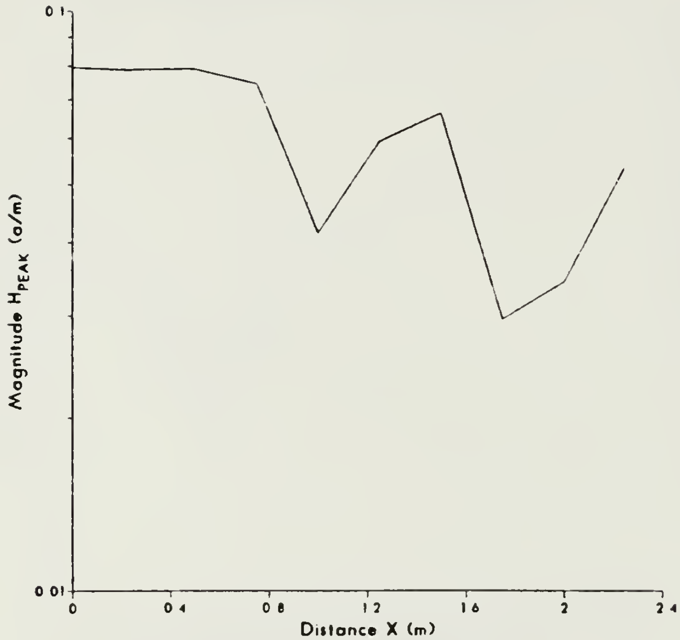
PHASE VS DISTANCE. FREQ = 300 MHZ. d=.25m
10 element uniform quad array z=300 ohm switched feed



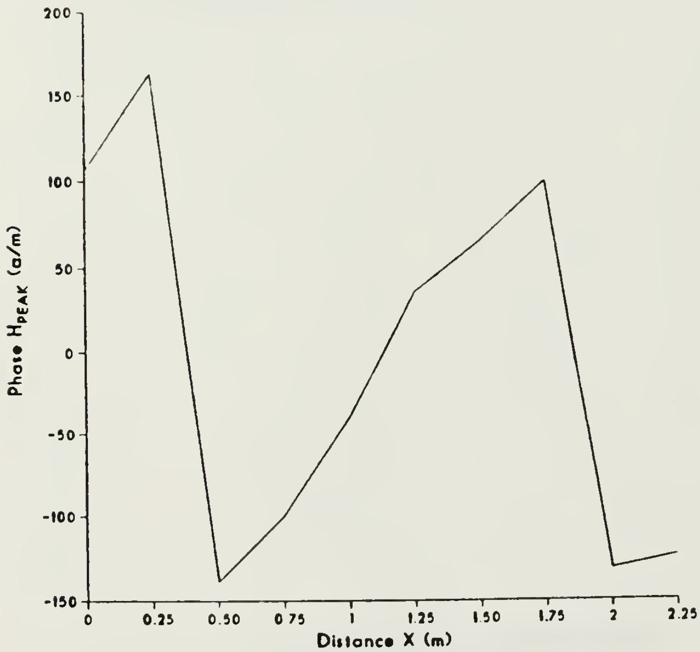

MAGNITUDE VS DISTANCE. FREQ = 400 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched
Magnitude H_{PEAK} (a/m)
0.1
0.01
0.001
0
0.4
0.8
1.2
1.6
2
2.4
Distance X (m)

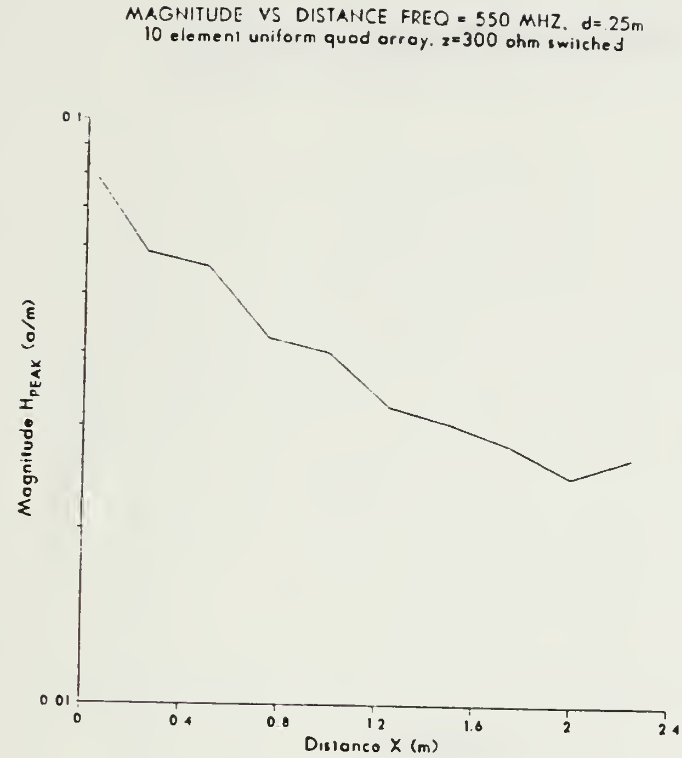

PHASE VS DISTANCE. FREQ = 400 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched feed
Phase H_{PEAK} (a/m)
150
100
50
0
-50
-100
-150
-200
0
0.25
0.50
0.75
1
1.25
1.50
1.75
2
2.25
Distance X (m)

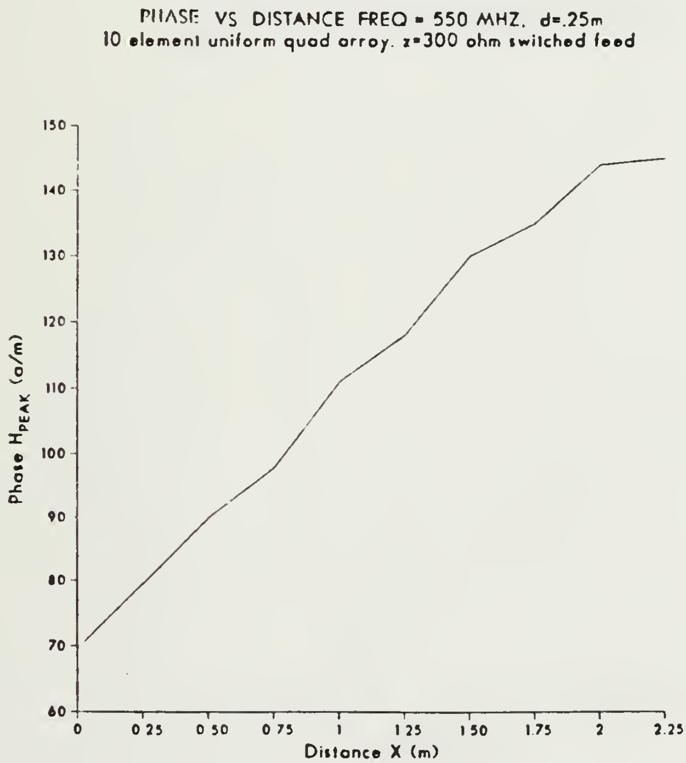
MAGNITUDE VS DISTANCE. FREQ = 450 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched



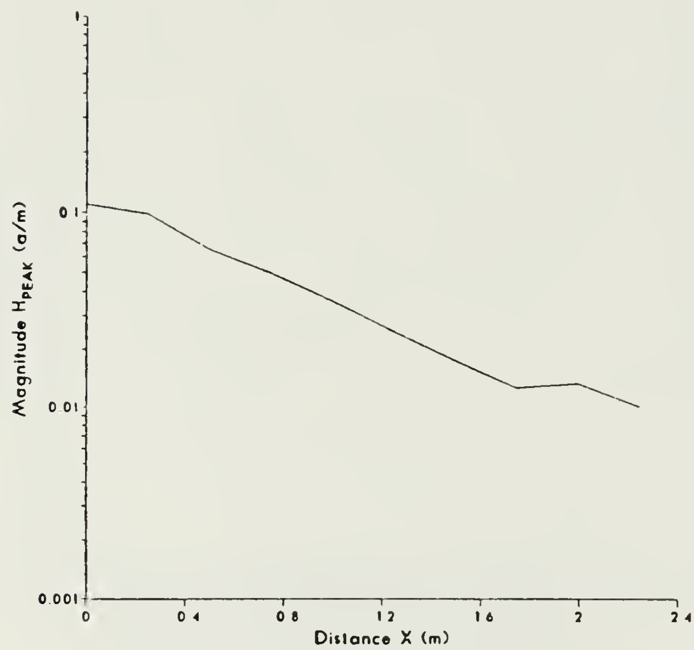
PHASE VS DISTANCE. FREQ = 450 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched feed



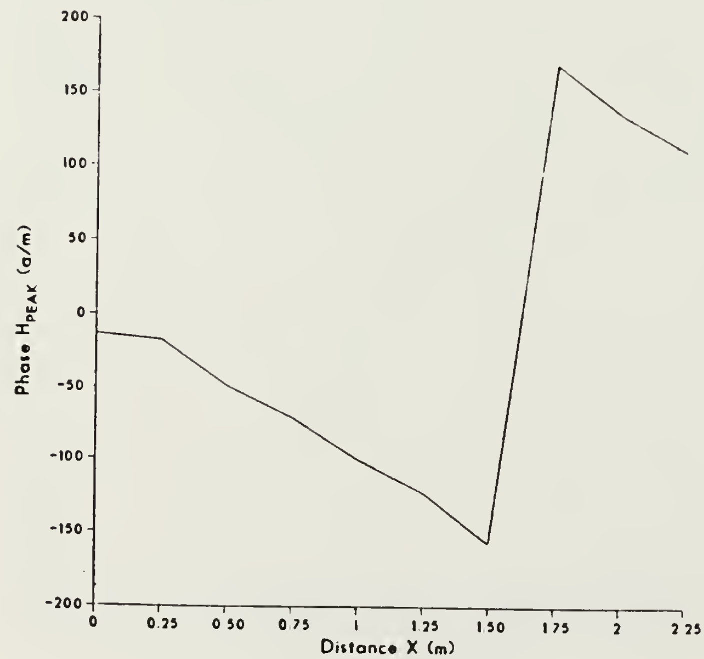

MAGNITUDE VS DISTANCE FREQ = 550 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched
Magnitude H_{PEAK} (a/m)
0.1
0.01
0
0.4
0.8
1.2
1.6
2
2.4
Distance X (m)


PHASE VS DISTANCE FREQ = 550 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched feed
Phase H_{PEAK} (a/m)
150
140
130
120
110
100
90
80
70
60
0
0.25
0.50
0.75
1
1.25
1.50
1.75
2
2.25
Distance X (m)

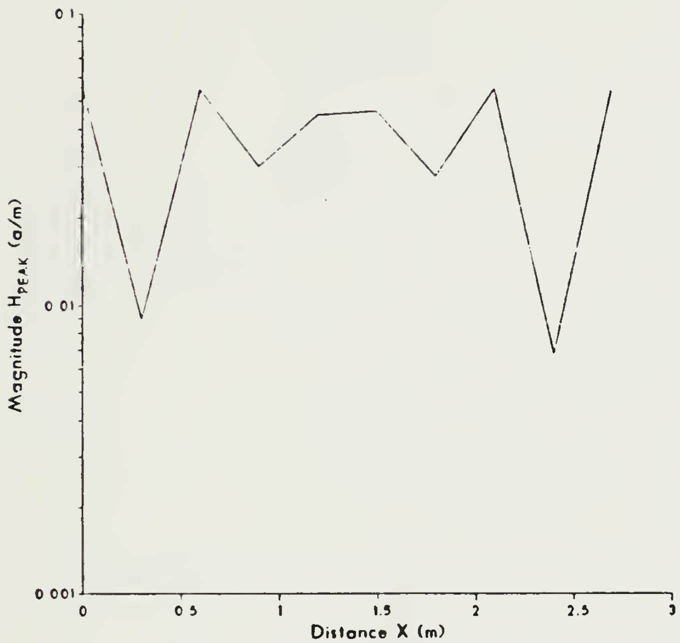
MAGNITUDE VS DISTANCE. FREQ = 650 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched



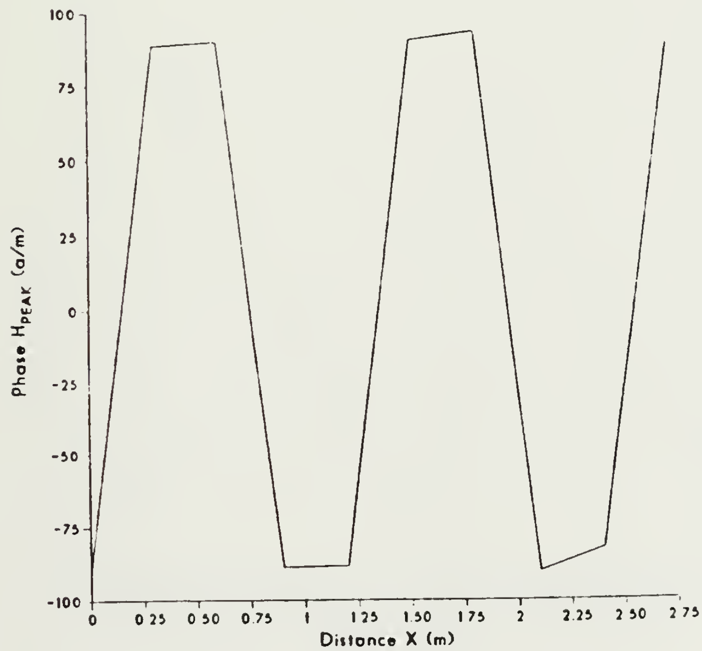
PHASE VS DISTANCE. FREQ = 650 MHZ. d=.25m
10 element uniform quad array. z=300 ohm switched feed



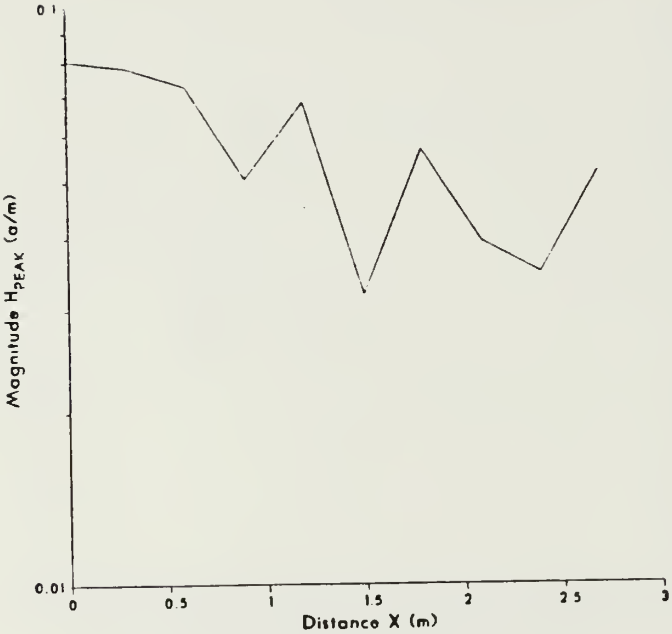
MAGNITUDE VS DISTANCE. FREQ = 200 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched



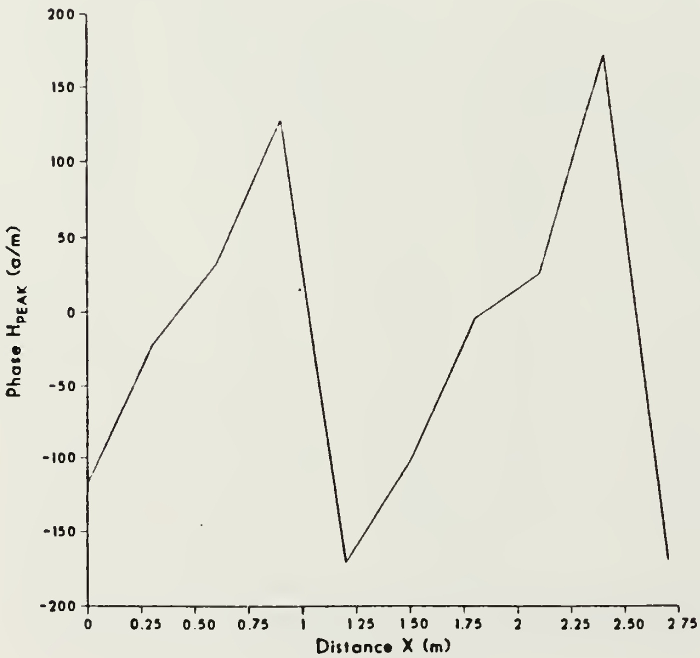
PHASE VS DISTANCE. FREQ = 200 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched feed



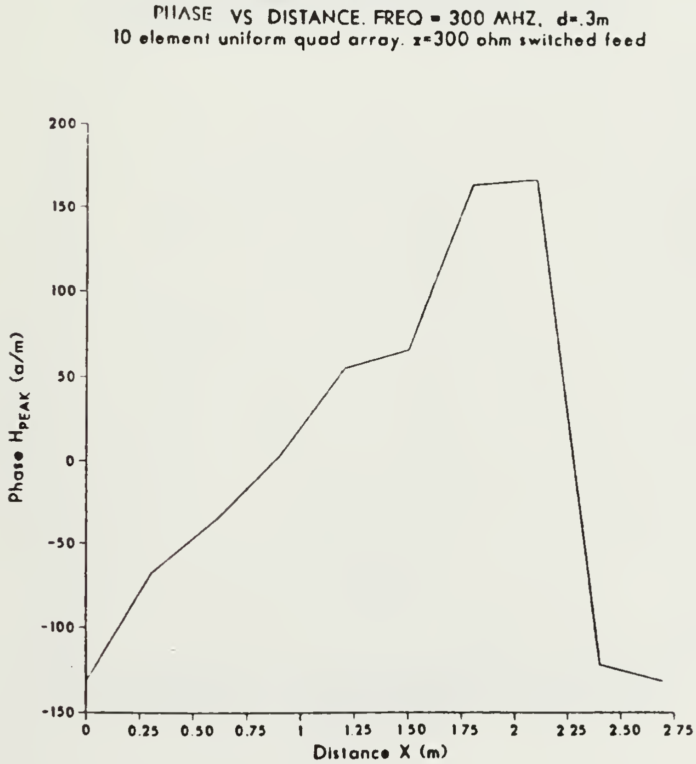
MAGNITUDE VS DISTANCE. FREQ = 250 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched



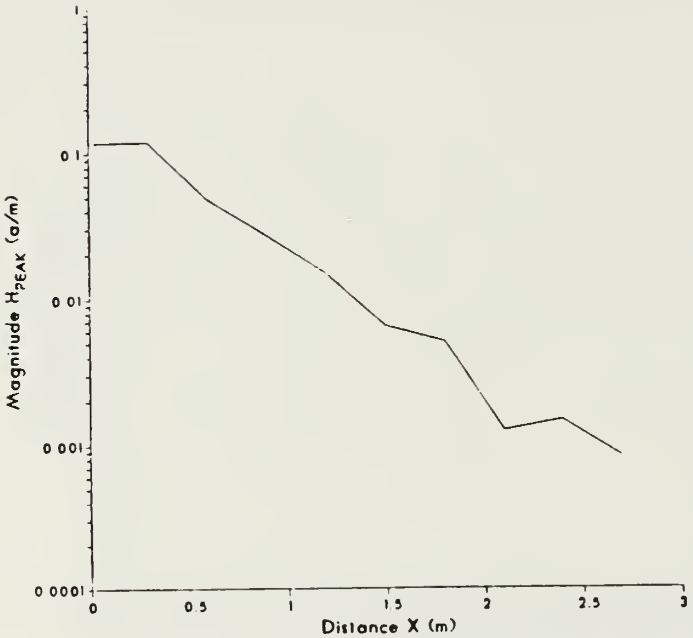
PHASE VS DISTANCE. FREQ = 250 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched feed



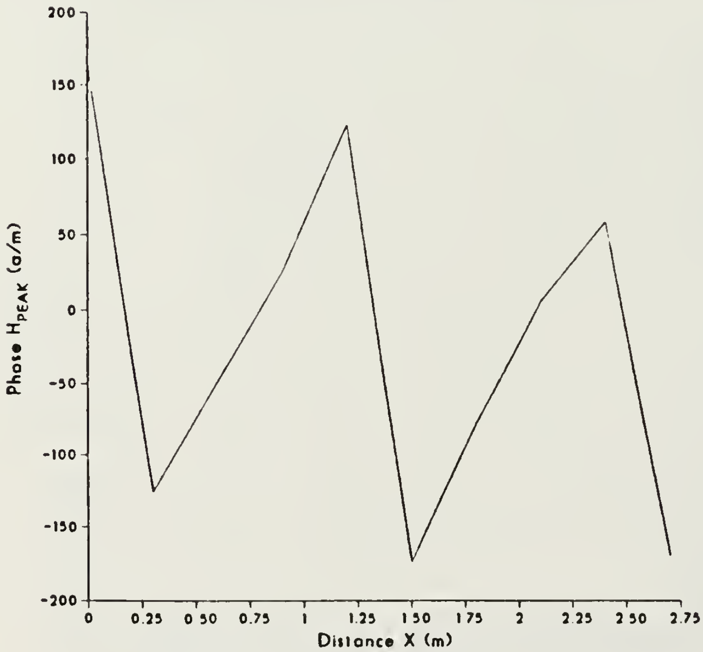

MAGNITUDE VS DISTANCE. FREQ = 300 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched
Magnitude H PEAK (a/m)
1
0.1
0.01
0.001
0
0.5
1
1.5
2
2.5
3
Distance X (m)


PHASE VS DISTANCE. FREQ = 300 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched feed
Phase H PEAK (a/m)
200
150
100
50
0
-50
-100
-150
0
0.25
0.50
0.75
1
1.25
1.50
1.75
2
2.25
2.50
2.75
Distance X (m)

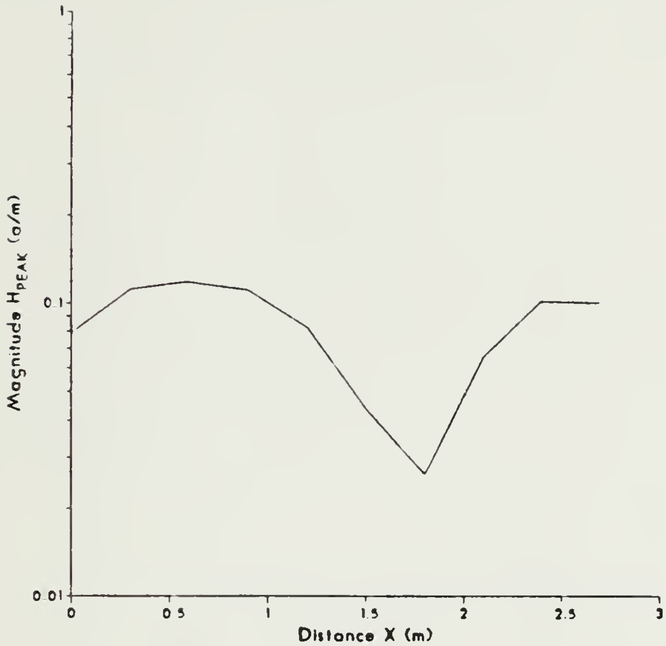
MAGNITUDE VS DISTANCE. FREQ = 350 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched



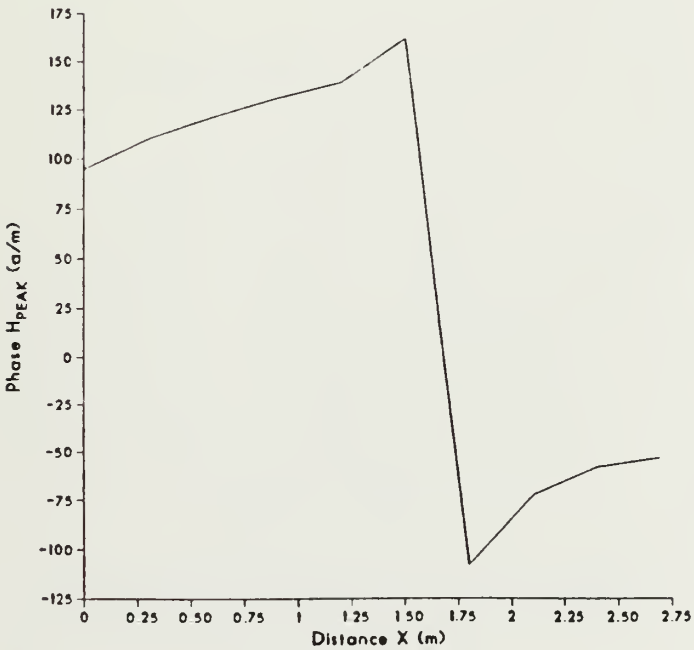
PHASE VS DISTANCE. FREQ = 350 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched feed



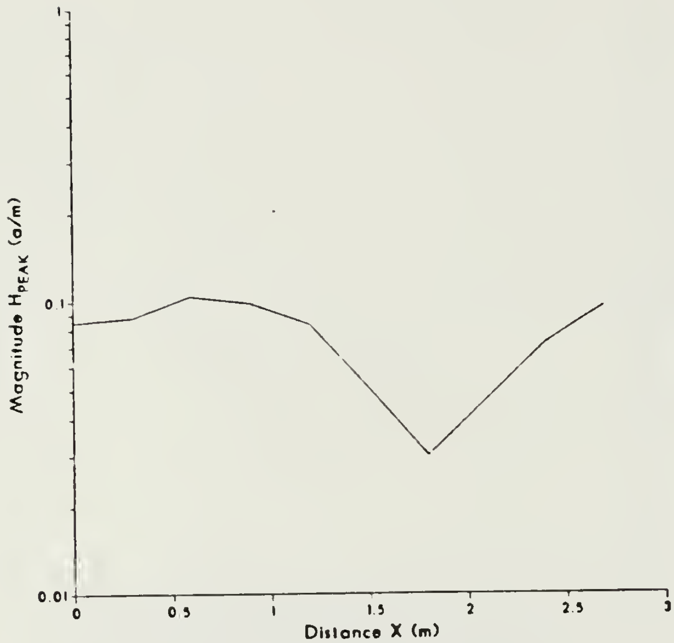
MAGNITUDE VS DISTANCE FREQ = 450 MHZ. d= 3m
10 element uniform quad array. z=300 ohm switched



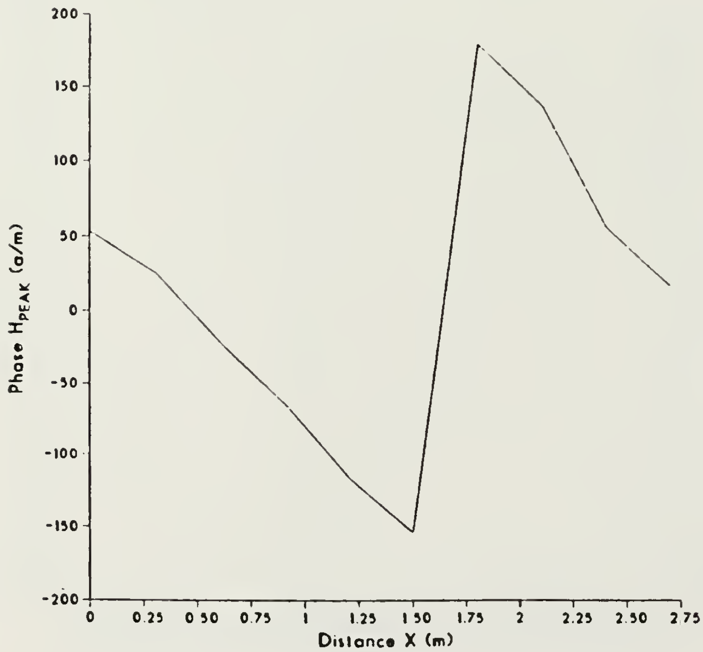
PHASE VS DISTANCE. FREQ = 450 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched feed



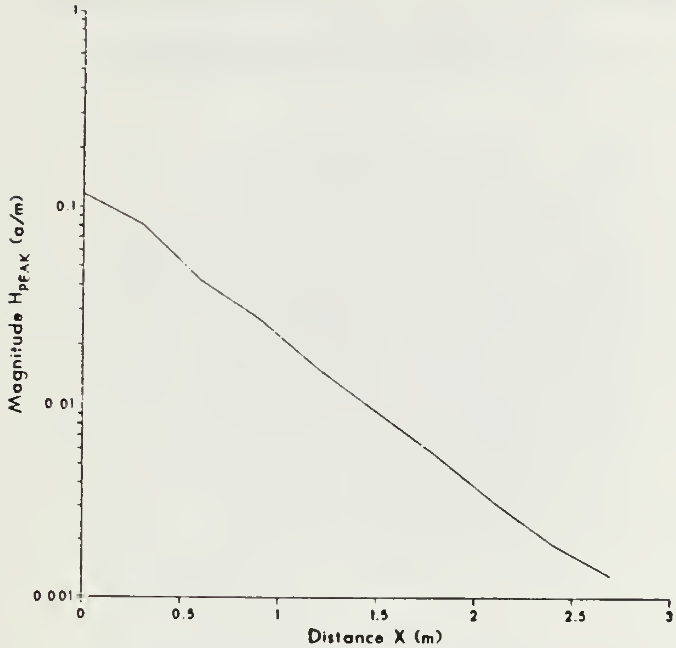
MAGNITUDE VS DISTANCE. FREQ = 550 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched



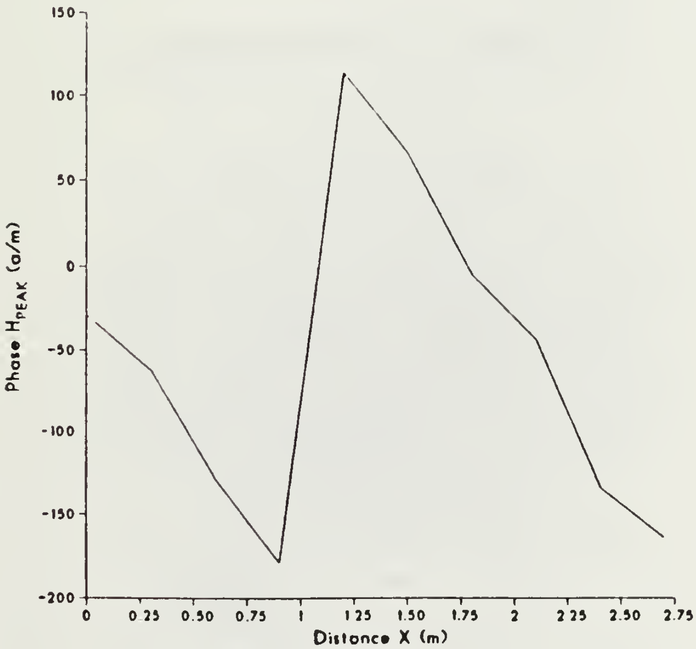
PHASE VS DISTANCE. FREQ = 580 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched feed



MAGNITUDE VS DISTANCE. FREQ = 650 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched

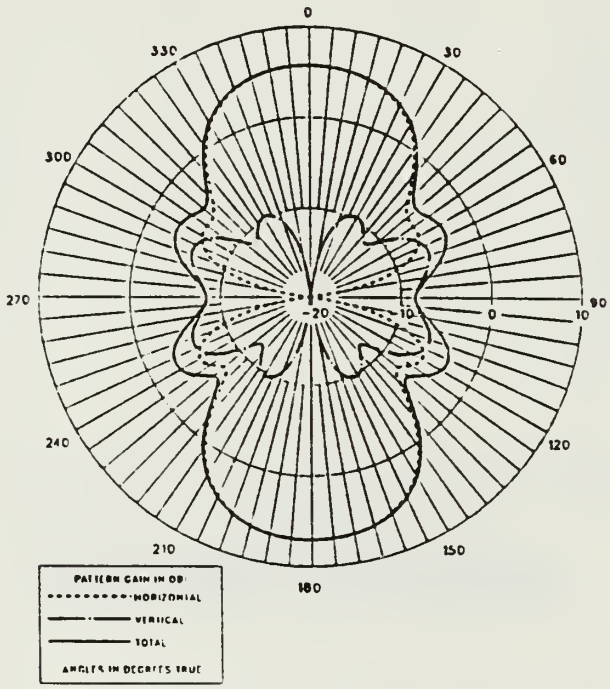


PHASE VS DISTANCE FREQ = 650 MHZ. d=.3m
10 element uniform quad array. z=300 ohm switched feed

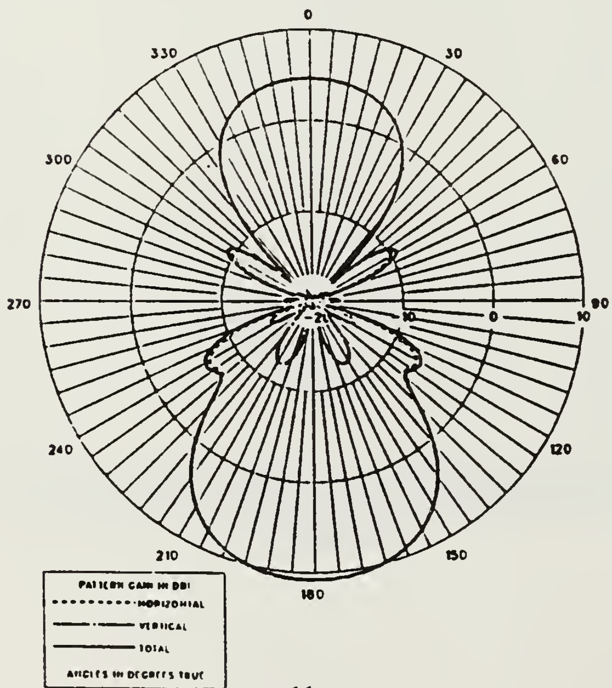


APPENDIX C. FAR FIELD RADIATION PATTERNS OF QUPA WITH A SWITCHED FEED TRANSMISSION LINE

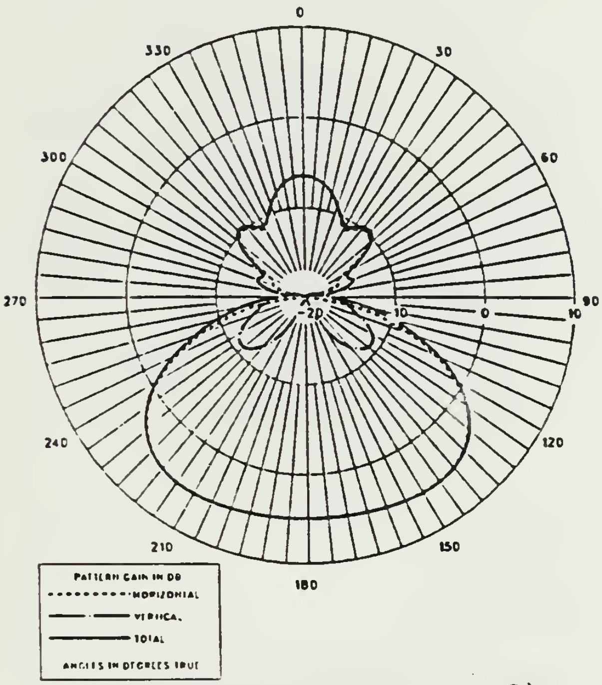
10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 200 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED



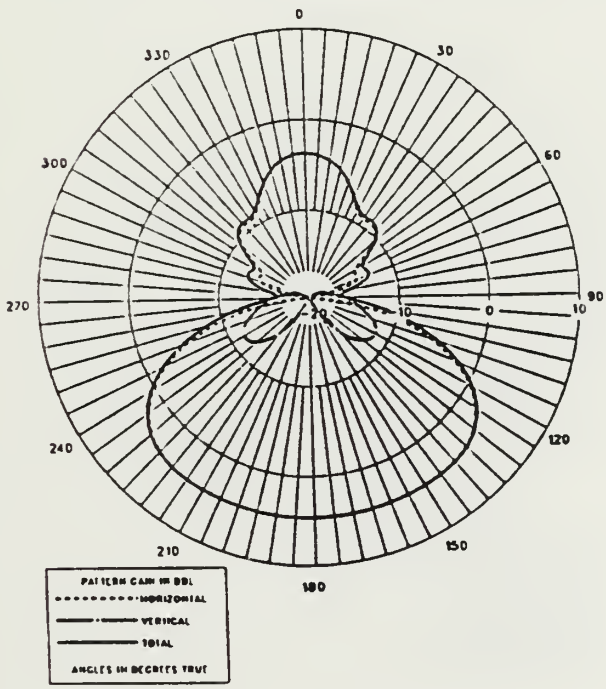
10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 250 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED



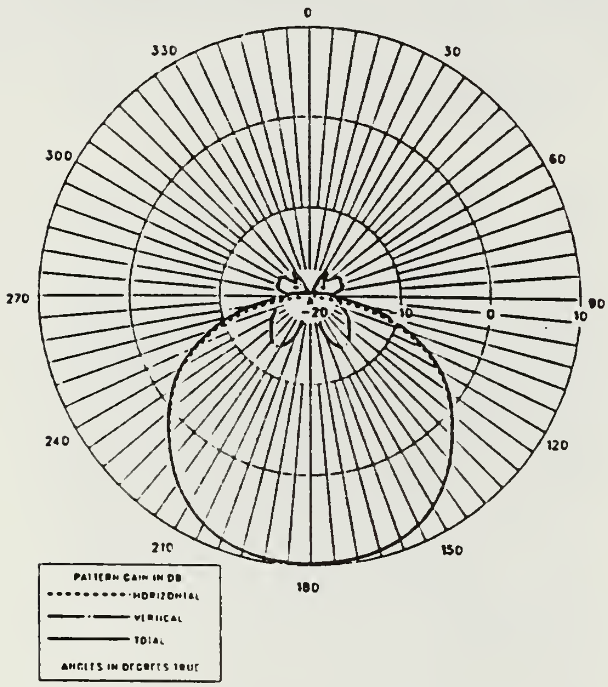
10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 300 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED



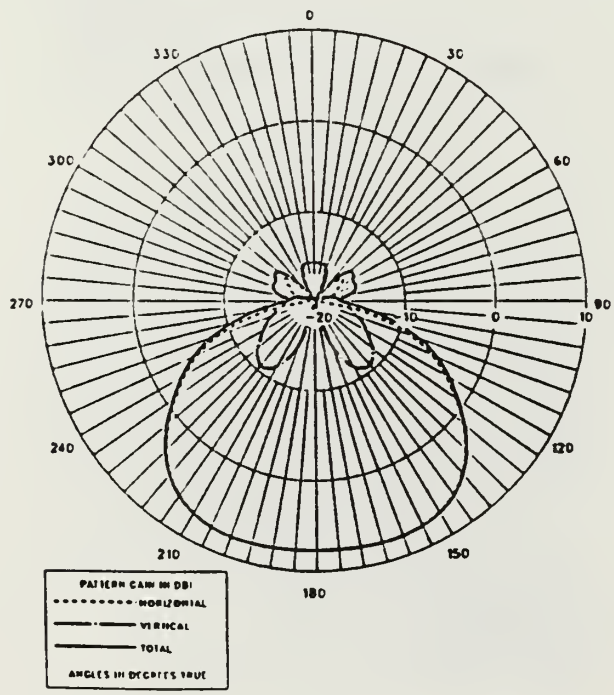
10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 310 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED



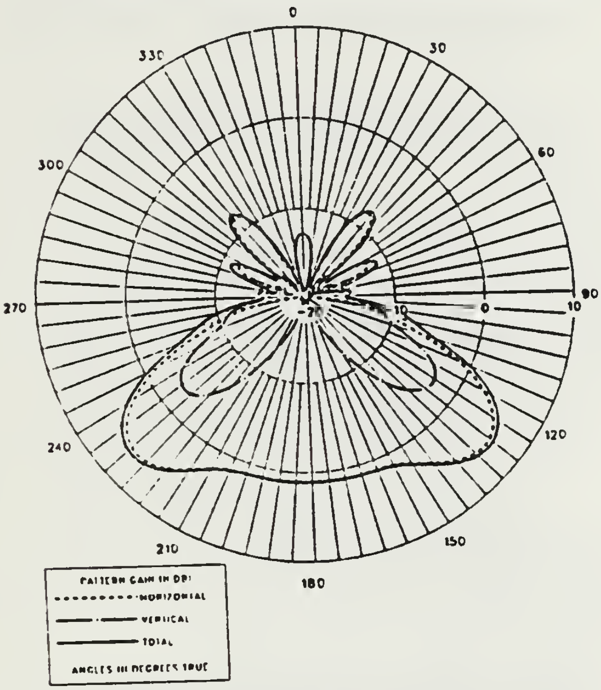
10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 340 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED



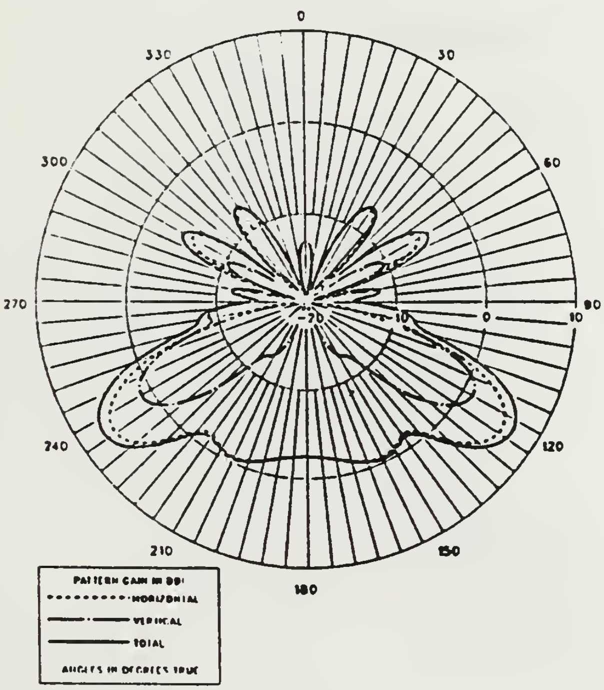
10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 350 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED



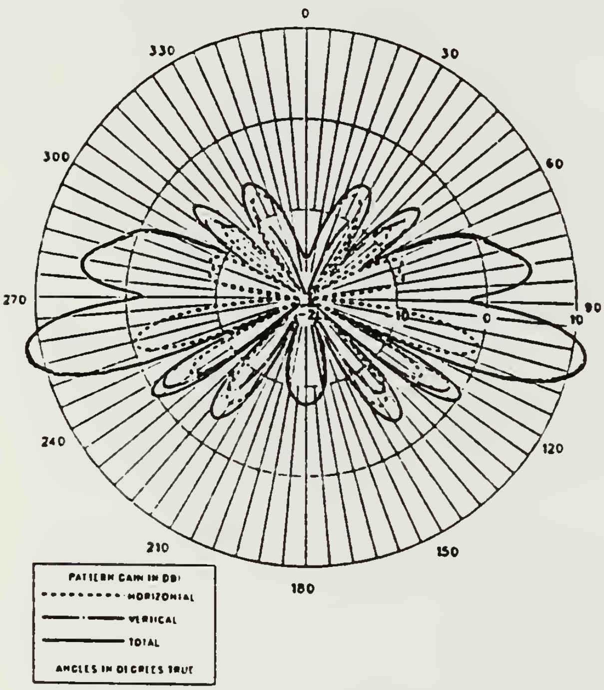
10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 400 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED



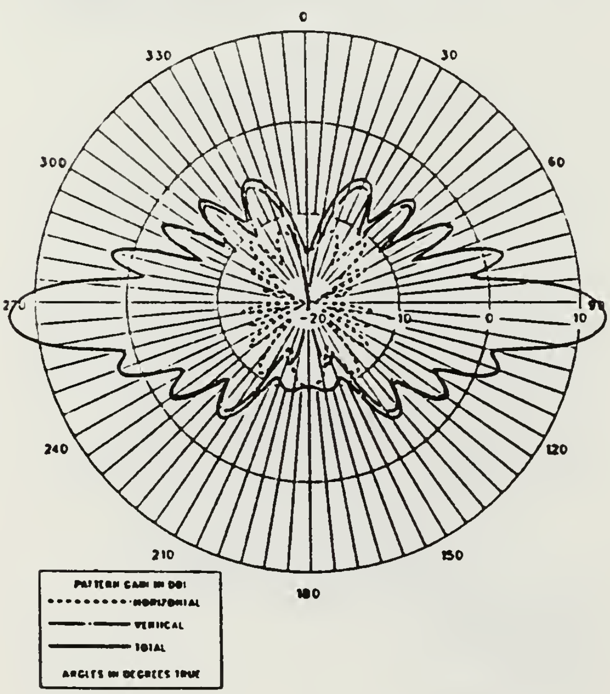
10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 425 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED



10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 500 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED

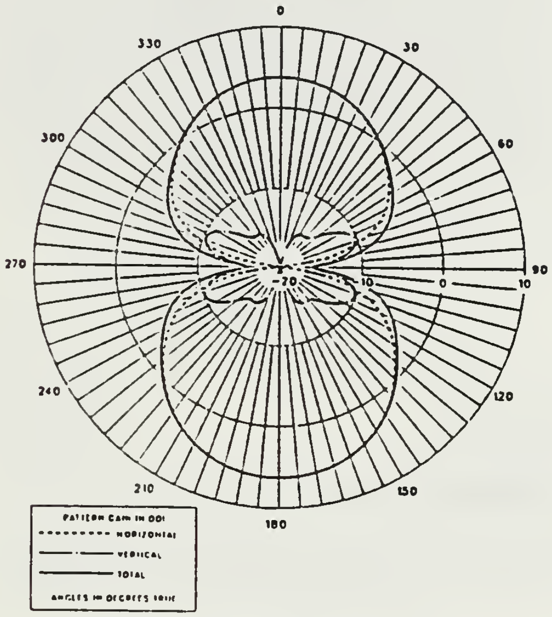


10 ELEMENT UNIFORM QUAD ARRAY (FREQ = 550 MHZ)
HORIZONTAL PATTERN. D=.25M , Z=300 OHM SWITCHED FEED

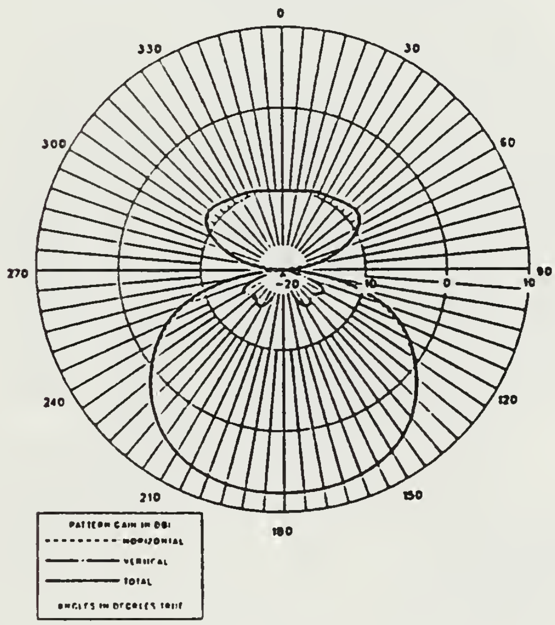


APPENDIX D. FAR FIELD RADIATION PATTERNS OF 9 AND 14 ELEMENT QLPAS IN FREE SPACE

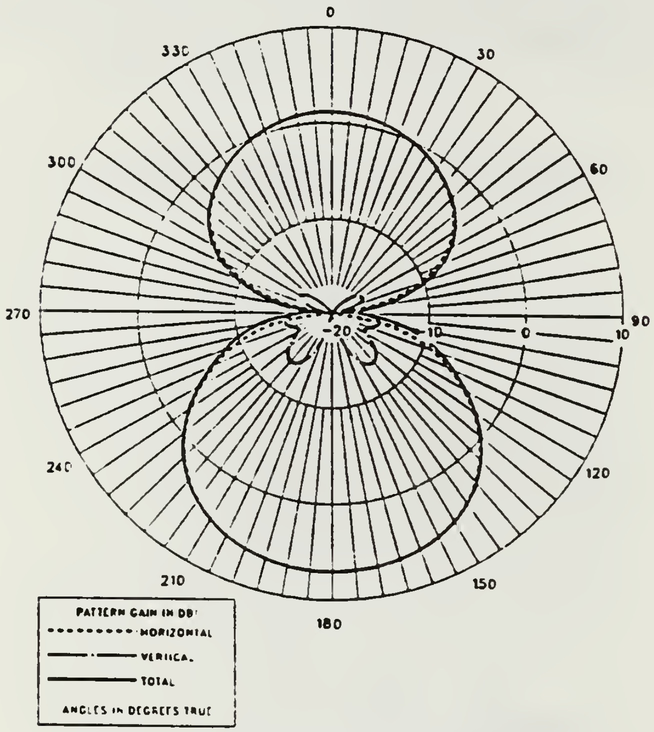
9 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 200 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M), Z=300 OHM SWITCHED FEED



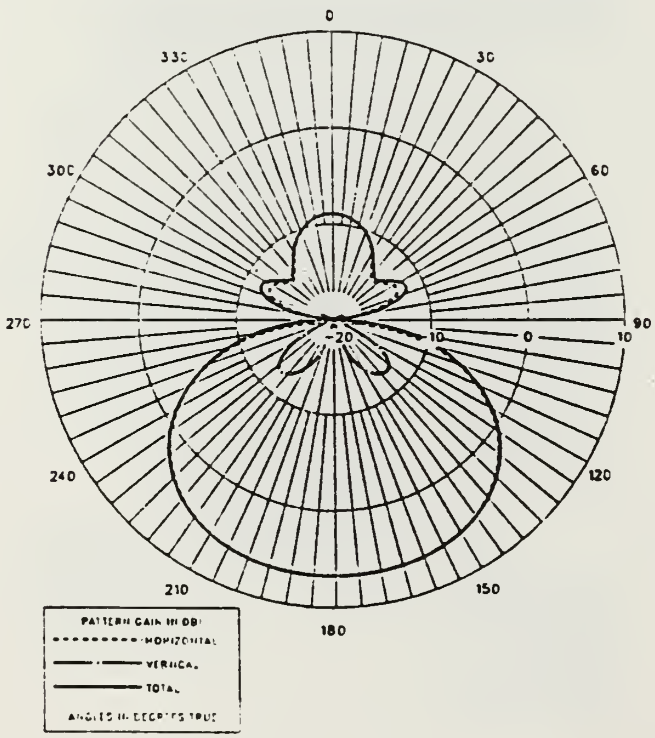
14 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 200 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



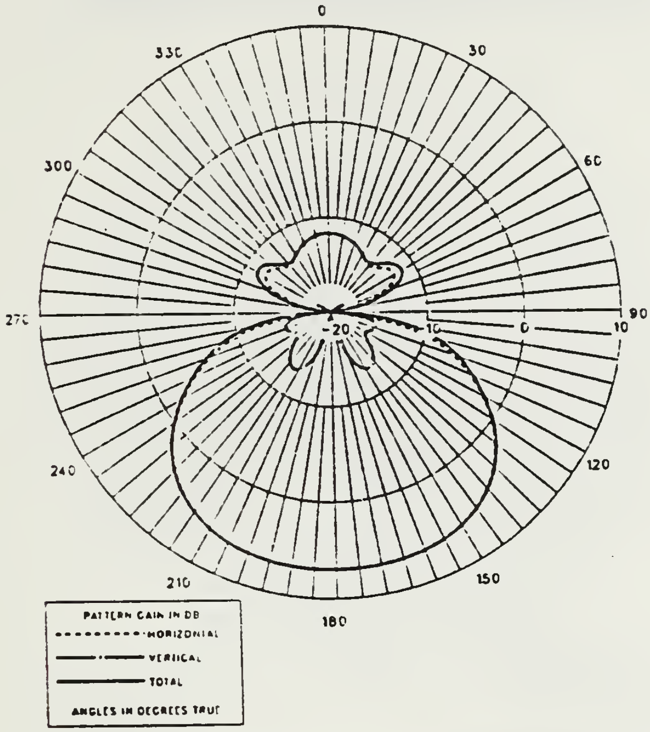
9 ELEMENT QUAD LOG–PERIODIC ARRAY (FREQ = 230 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M), Z=300 OHM SWITCHED FEED



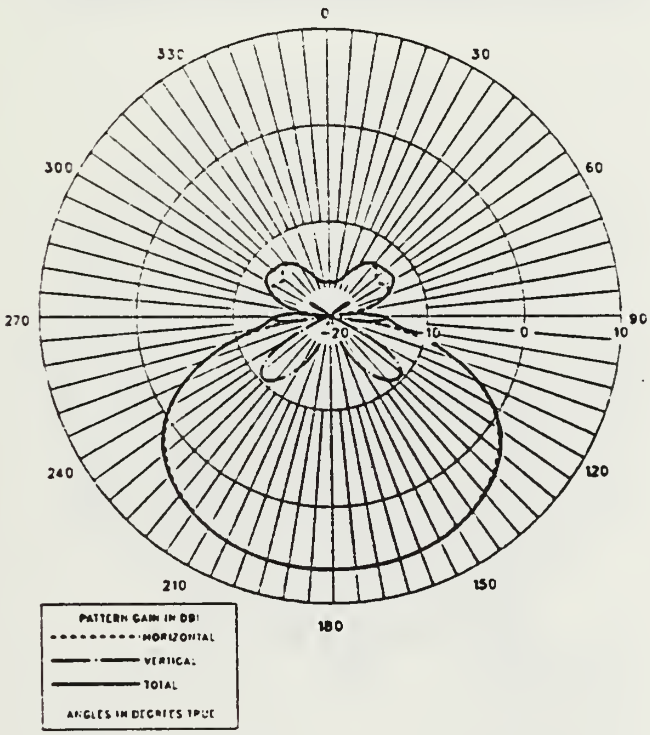
14 ELEMENT QUAD LOG–PERIODIC ARRAY (FREQ = 230 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



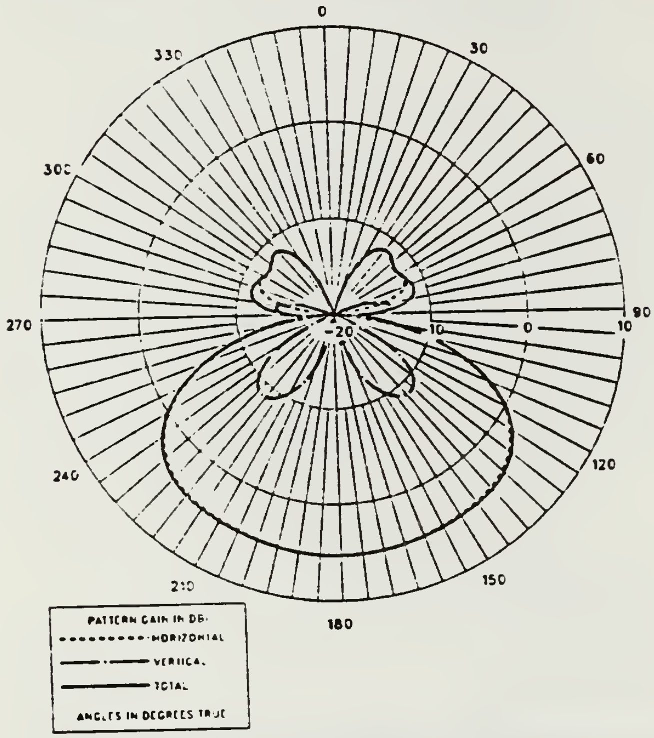
9 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 300 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M), Z=300 OHM SWITCHED FEED



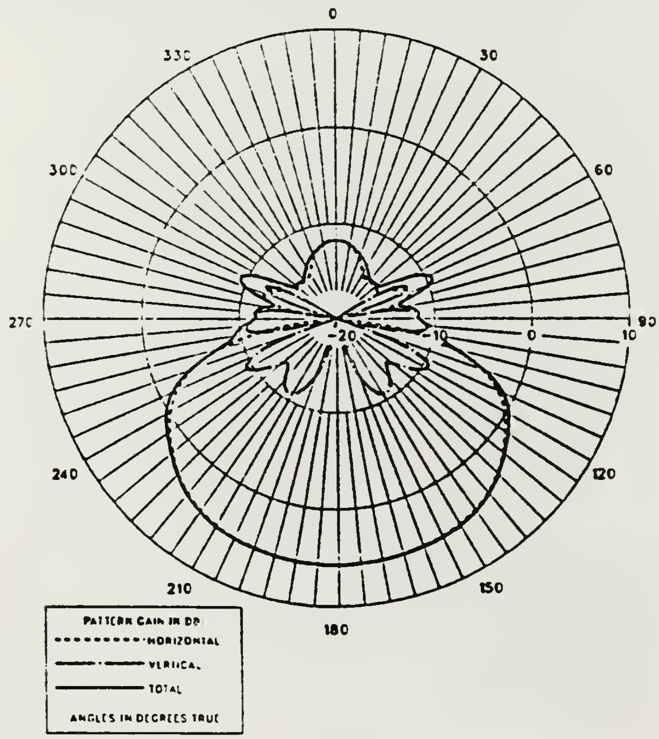
14 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 300 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



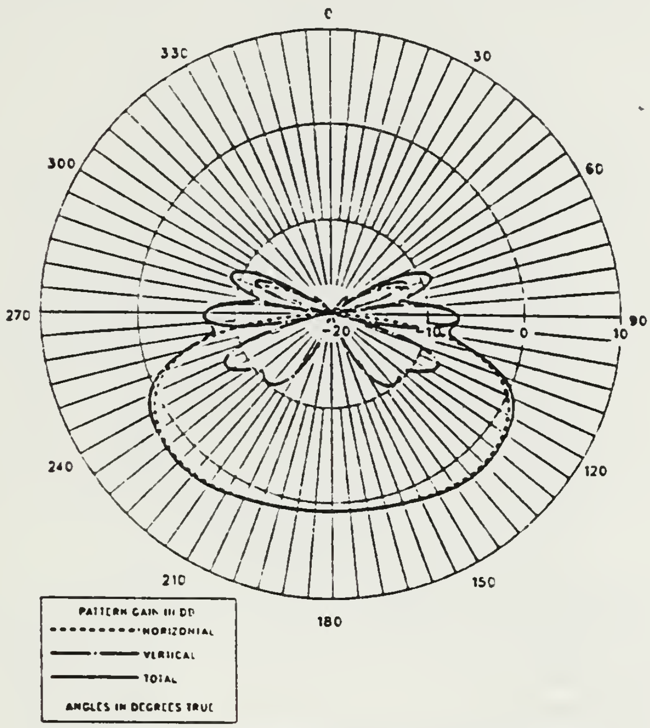
9 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 340 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M), Z=300 OHM SWITCHED FEED



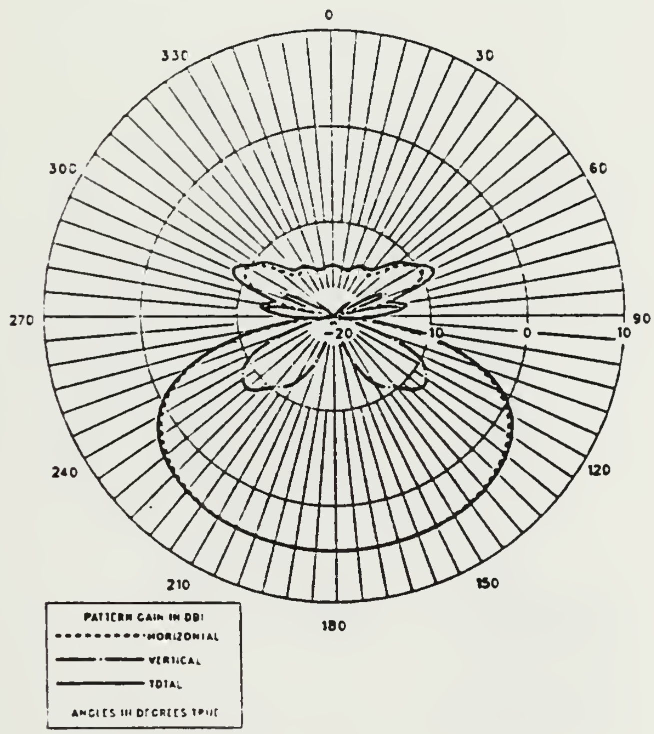
14 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 340 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



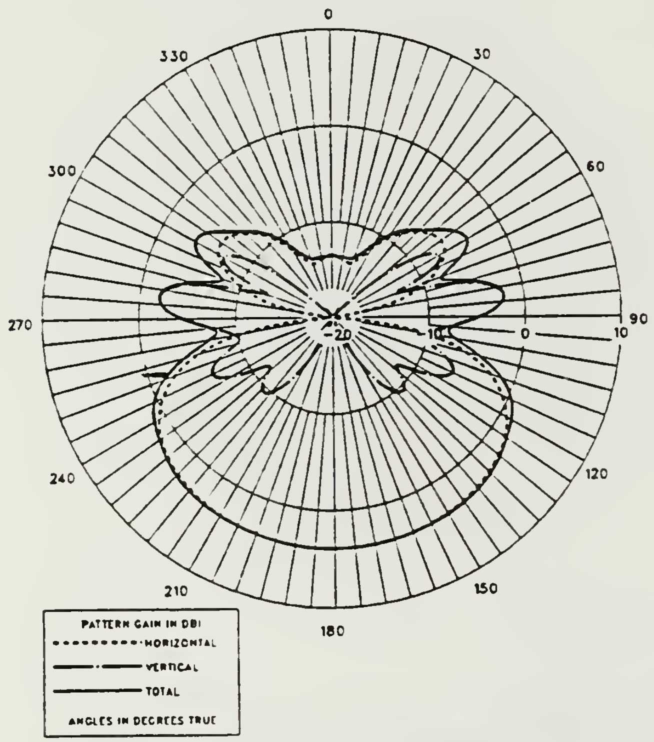
9 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 450 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M), Z=300 OHM SWITCHED FEED



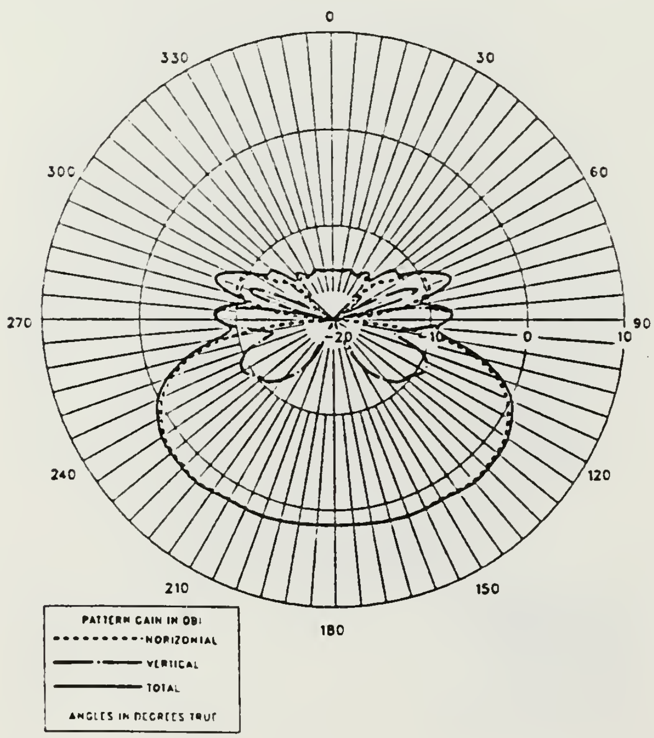
14 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 450 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



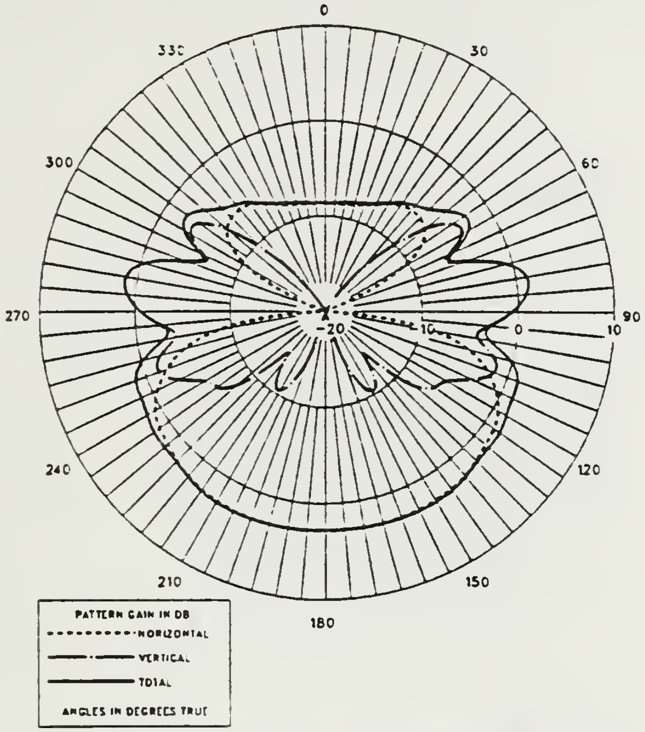
9 ELEMENT QUAD LOG–PERIODIC ARRAY (FREQ = 560 MHZ)
TAU=.915, SIGMA=.125 (DUPA=.25M) , Z=300 OHM SWITCHED FEED



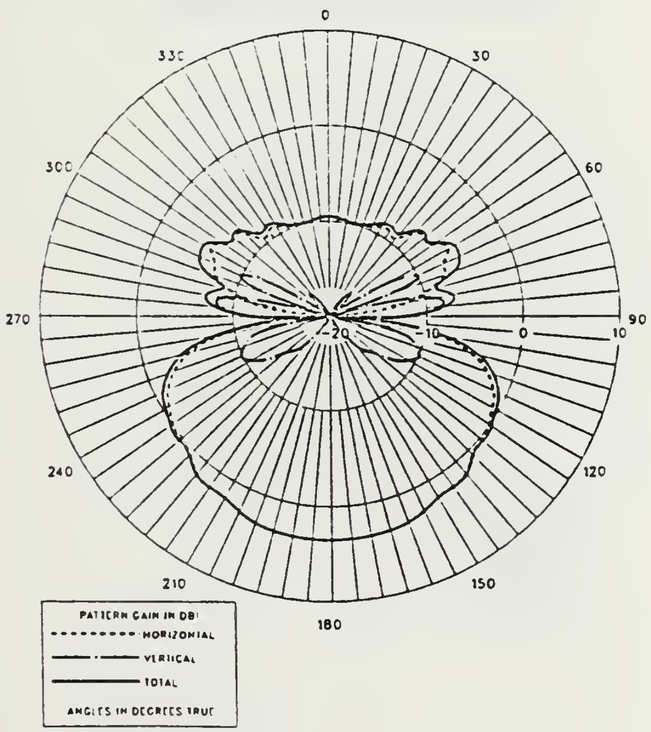
14 ELEMENT QUAD LOG–PERIODIC ARRAY (FREQ = 560 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



9 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 600 MHZ)
TAU=.915, SIGMA=.125 (DUPA=.25M) , Z=300 OHM SWITCHED FEED

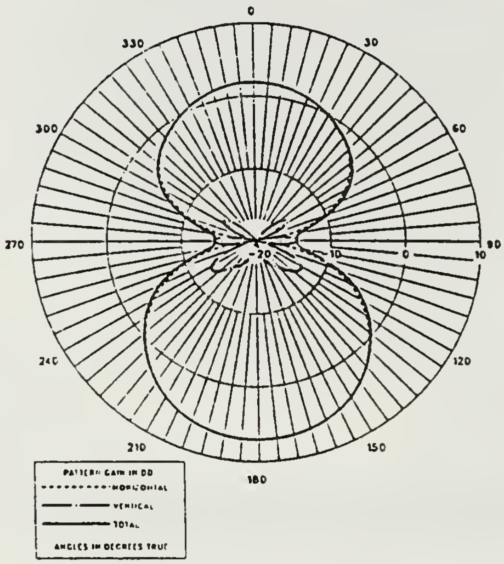


14 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 600 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED

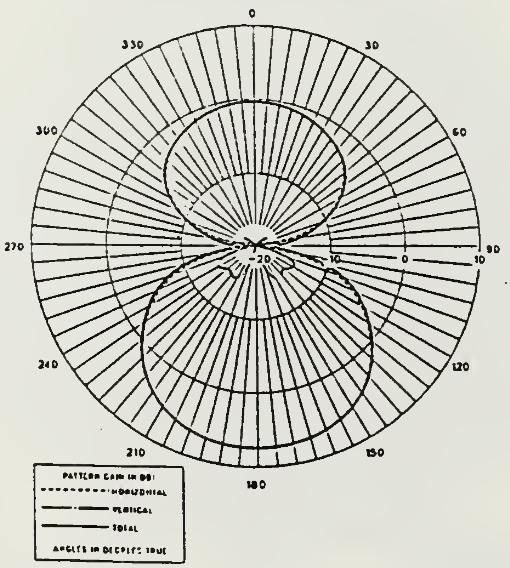


APPENDIX E. FAR FIELD RADIATION PATTERNS OF A 13 ELEMENT QLPA IN FREE SPACE

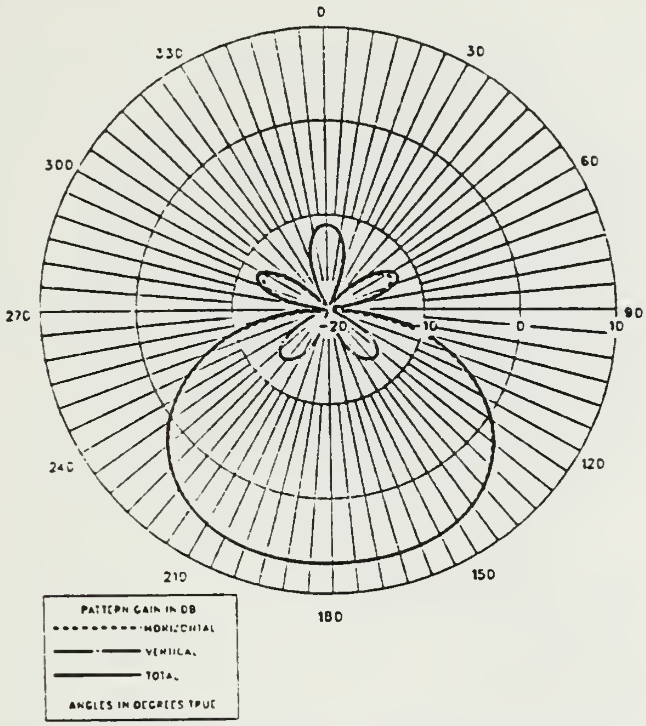
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 190 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



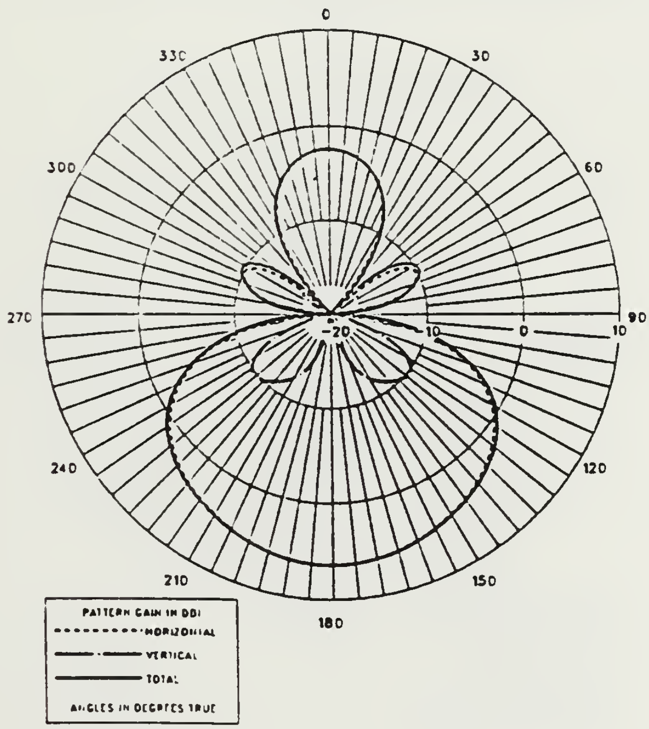
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 200 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



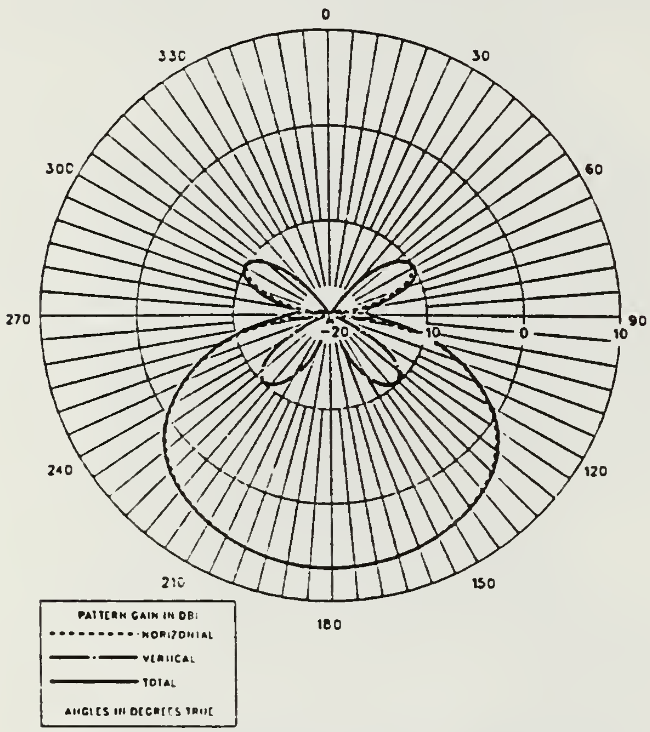
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 230 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



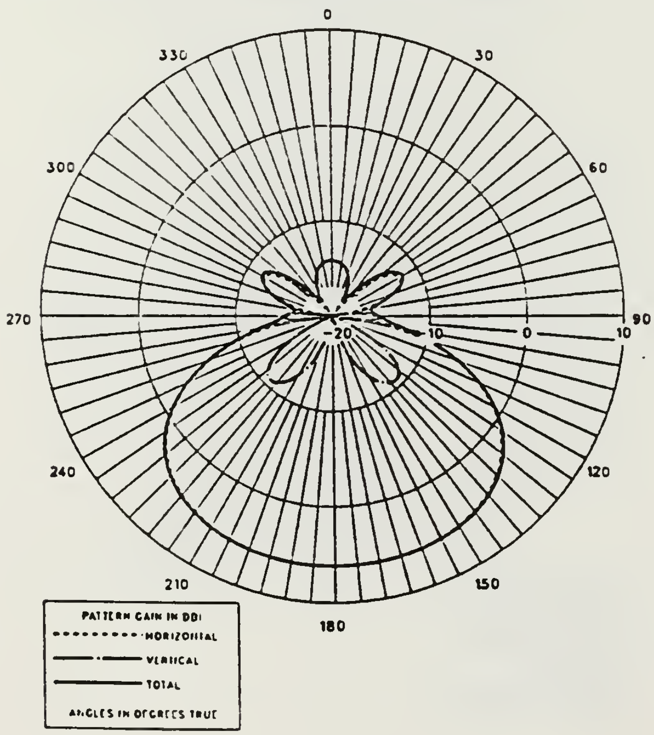
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 240 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



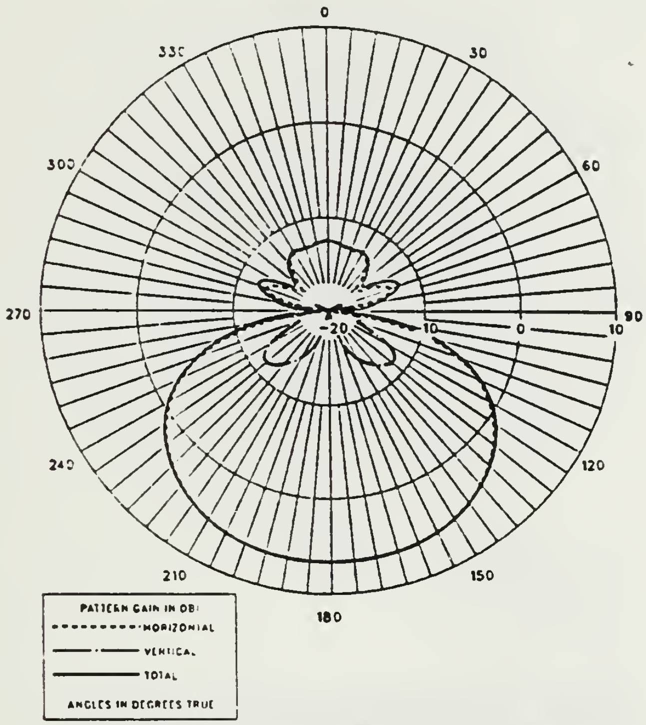
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 290 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



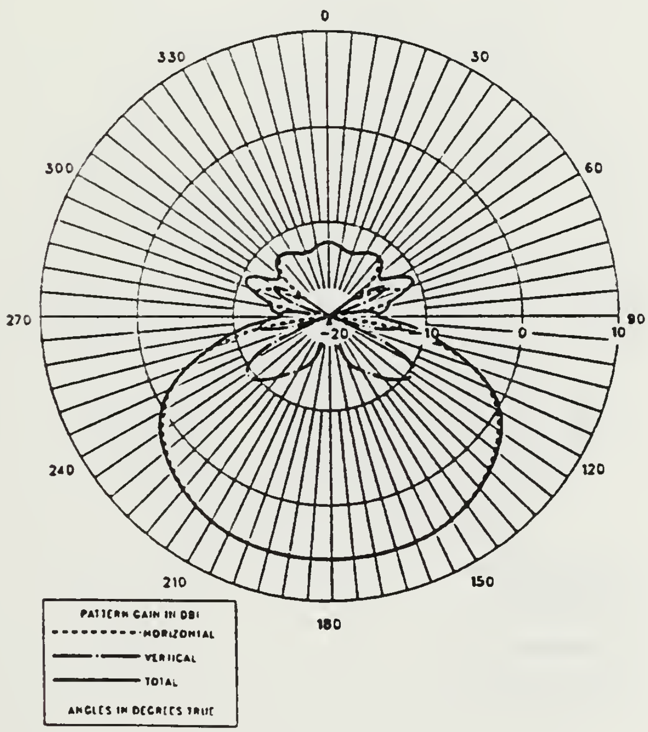
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 300 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



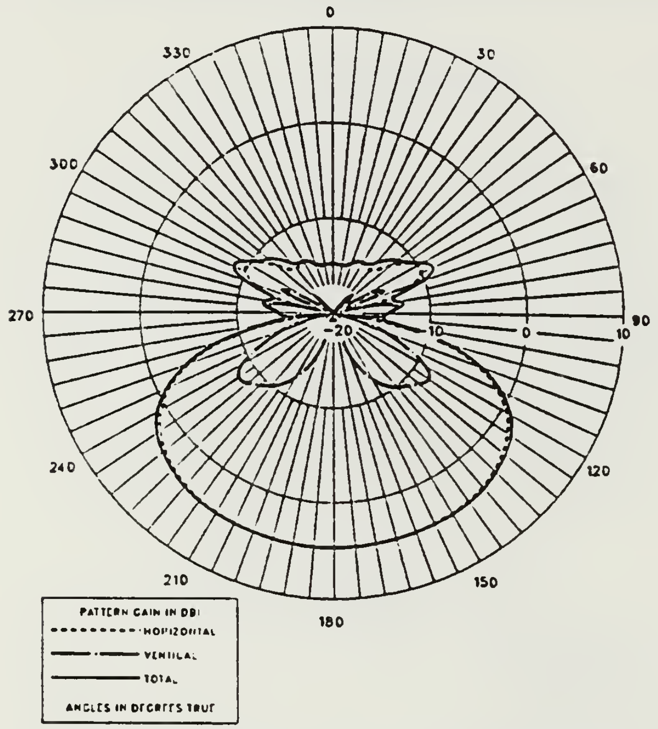
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 330 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



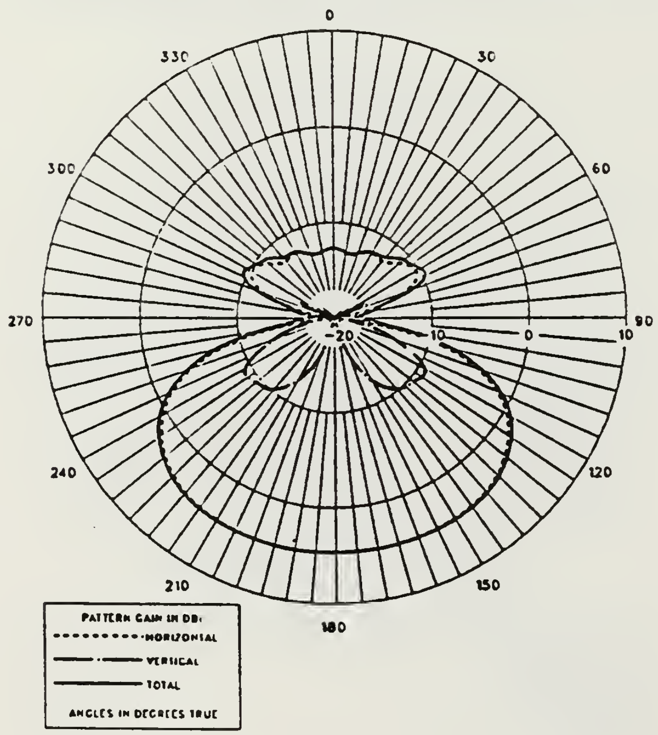
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 340 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



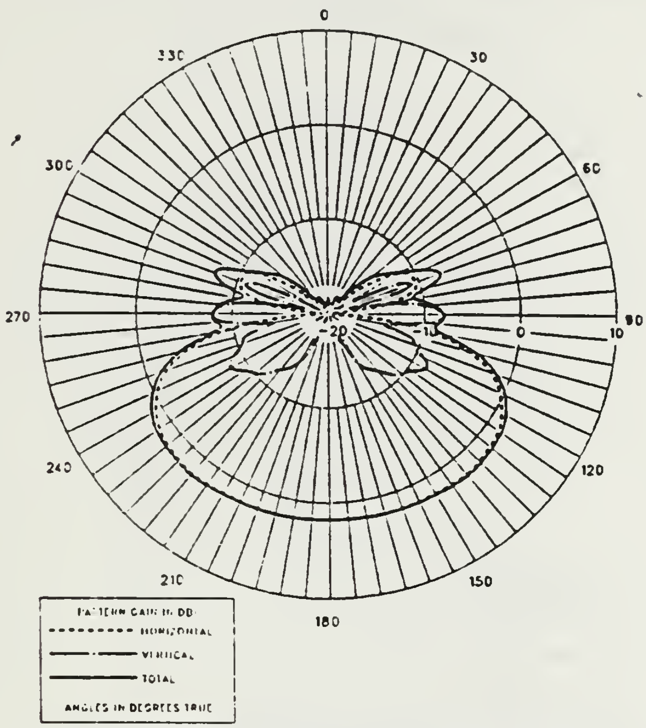
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 450 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



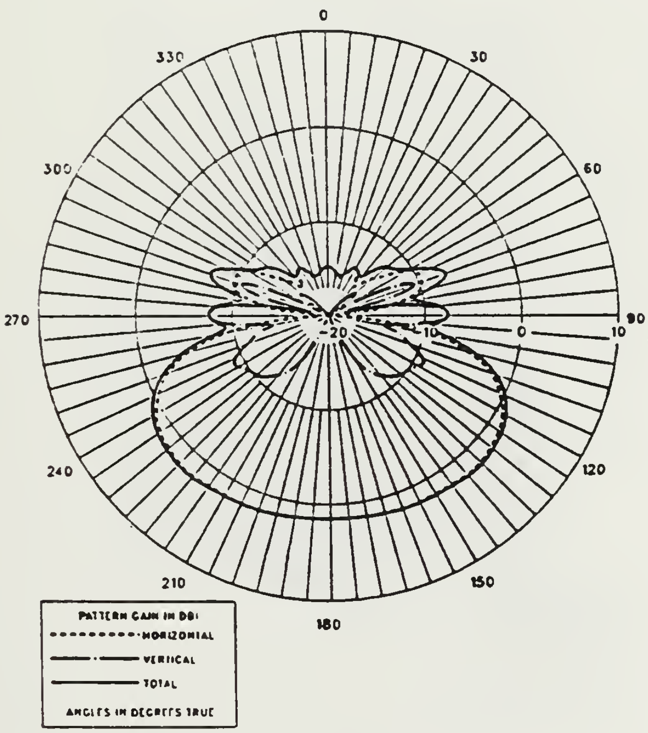
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 460 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



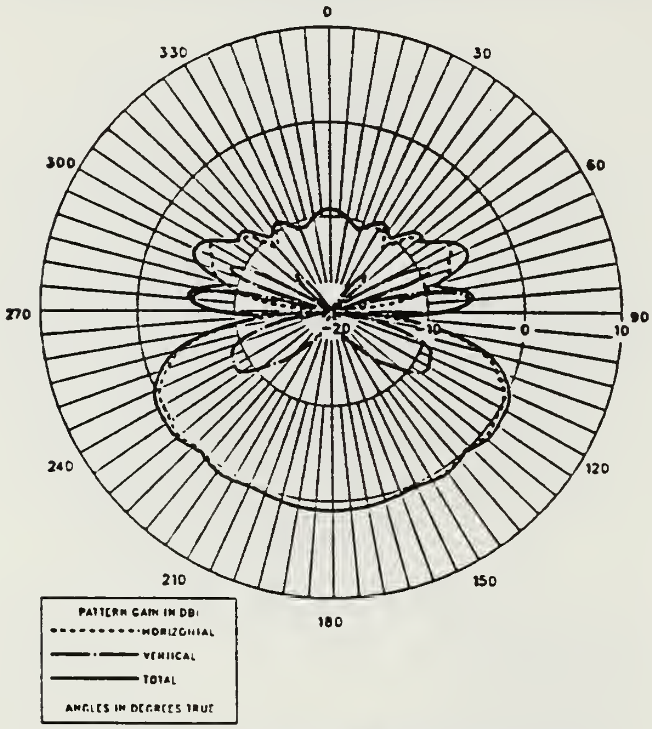
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 550 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



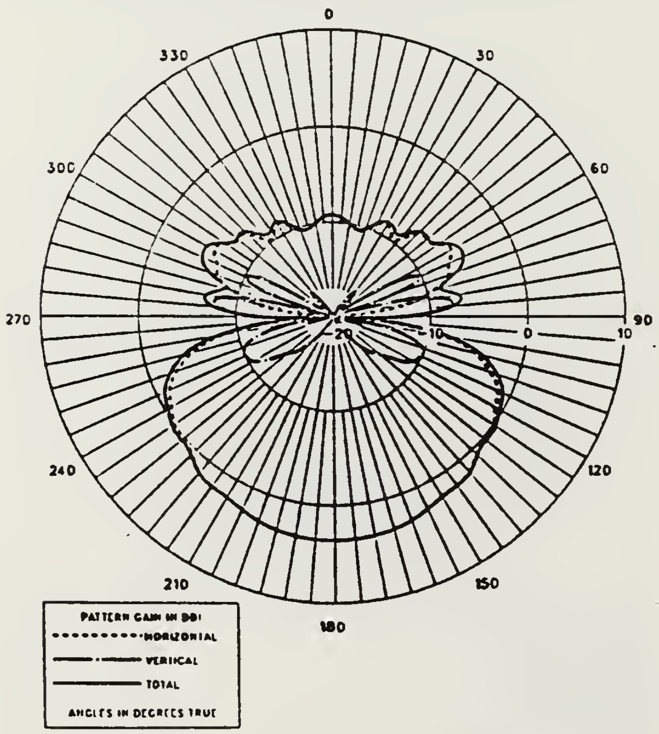
13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 560 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED



13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 590 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED

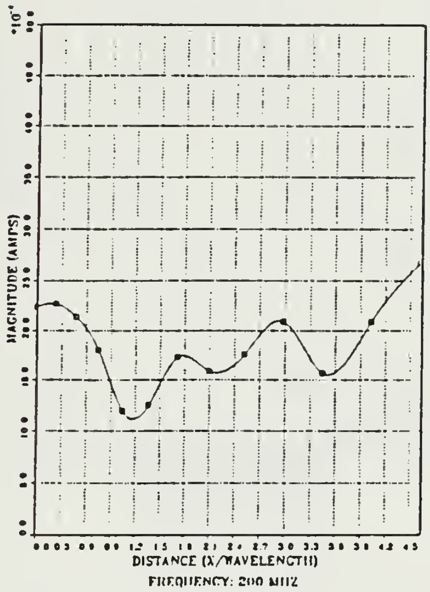


13 ELEMENT QUAD LOG-PERIODIC ARRAY (FREQ = 600 MHZ)
TAU=.915, SIGMA=.125, (DUPA=.25M) , Z=300 OHM SWITCHED FEED

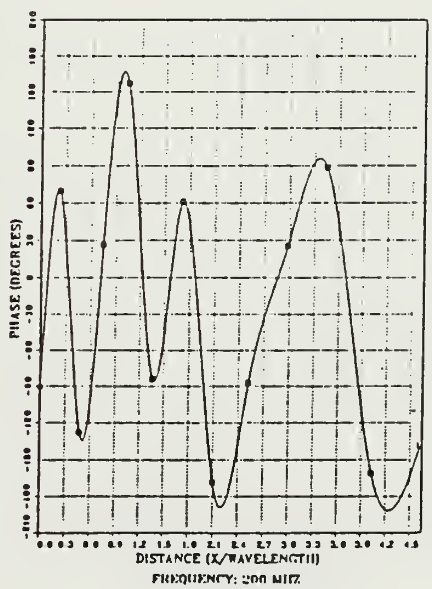


APPENDIX F. AMPLITUDE AND PHASE PLOTS OF A 13 ELEMENT QLPA IN FREE SPACE

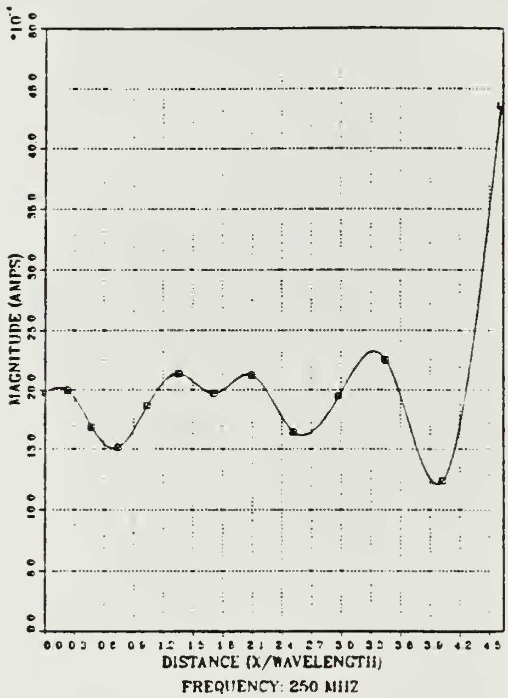
CURRENT AMPLITUDE



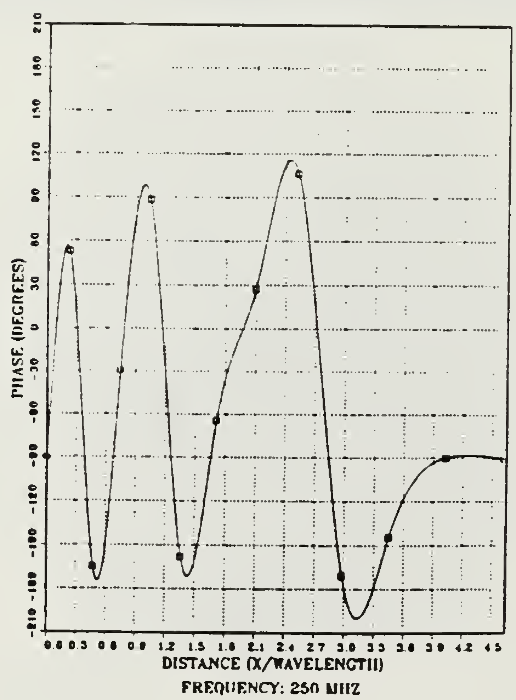
CURRENT PHASE



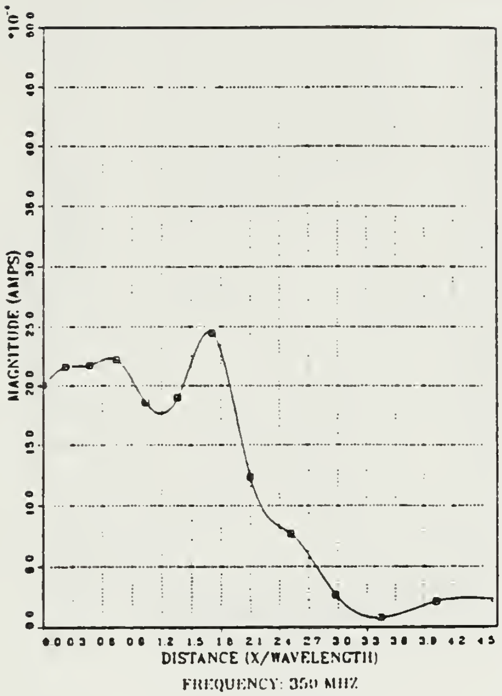
CURRENT AMPLITUDE



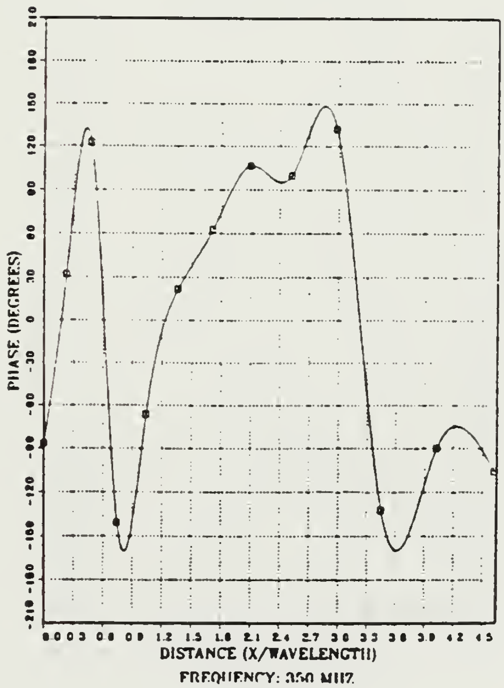
CURRENT PHASE



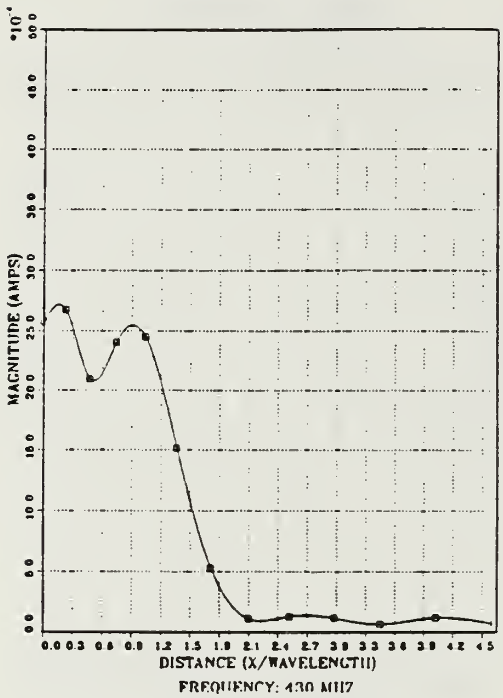
CURRENT AMPLITUDE



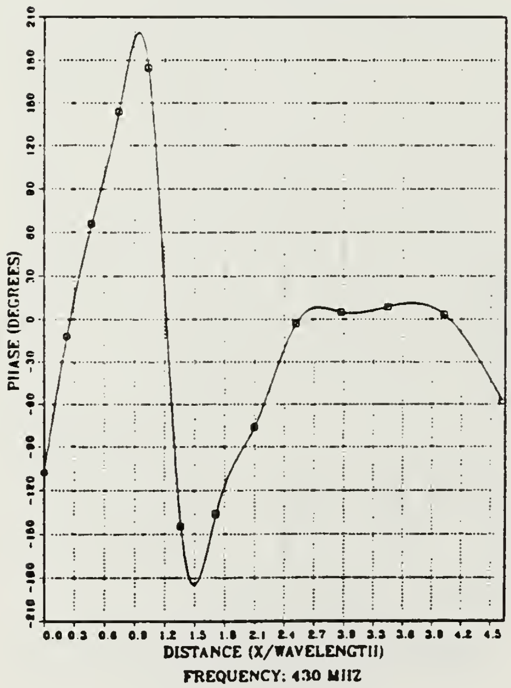
CURRENT PHASE



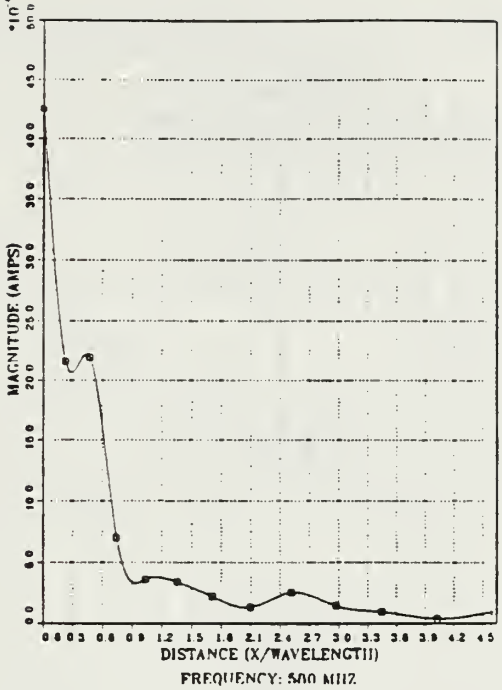
CURRENT AMPLITUDE



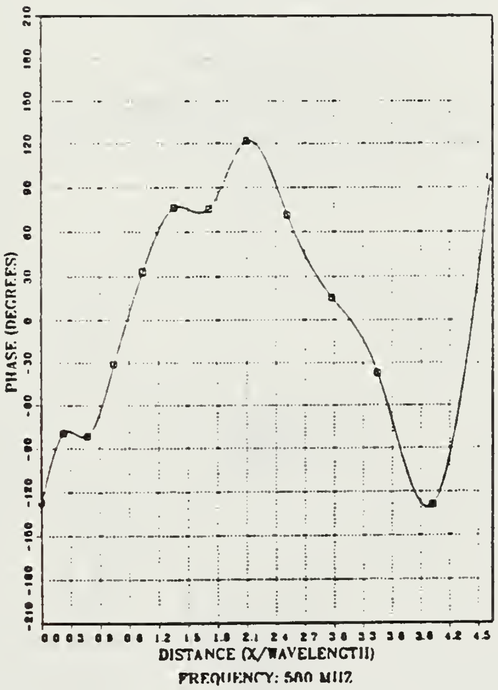
CURRENT PHASE



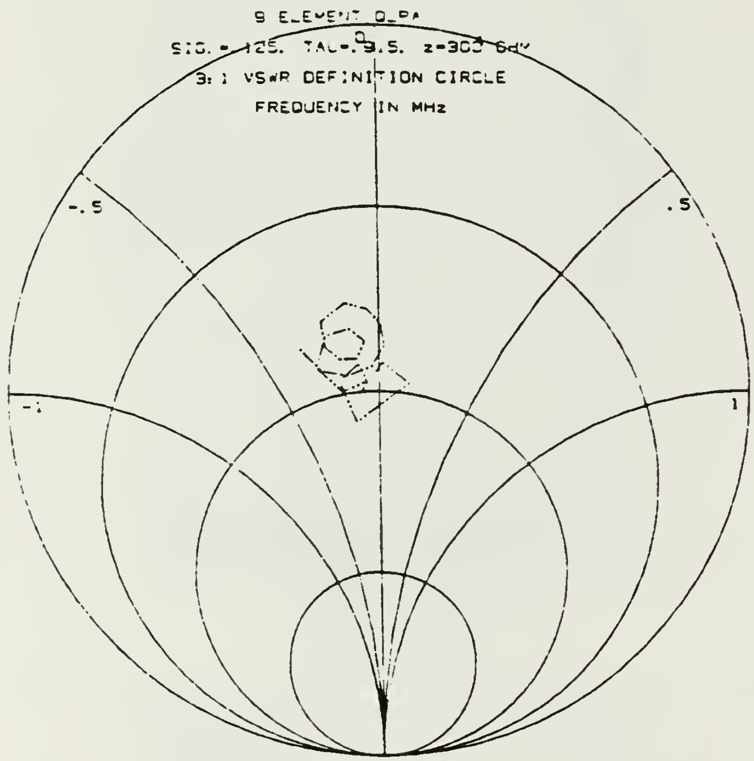
CURRENT AMPLITUDE

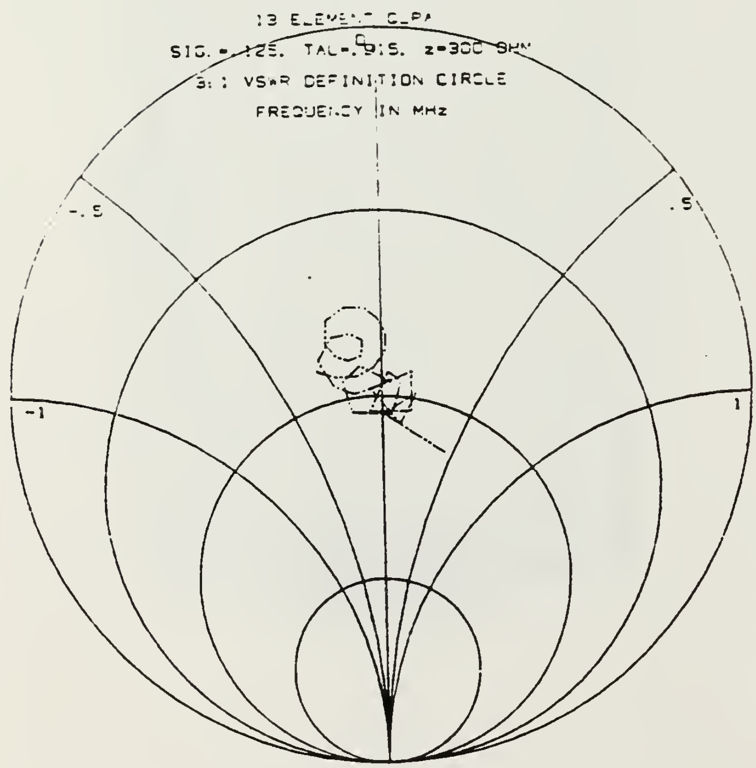


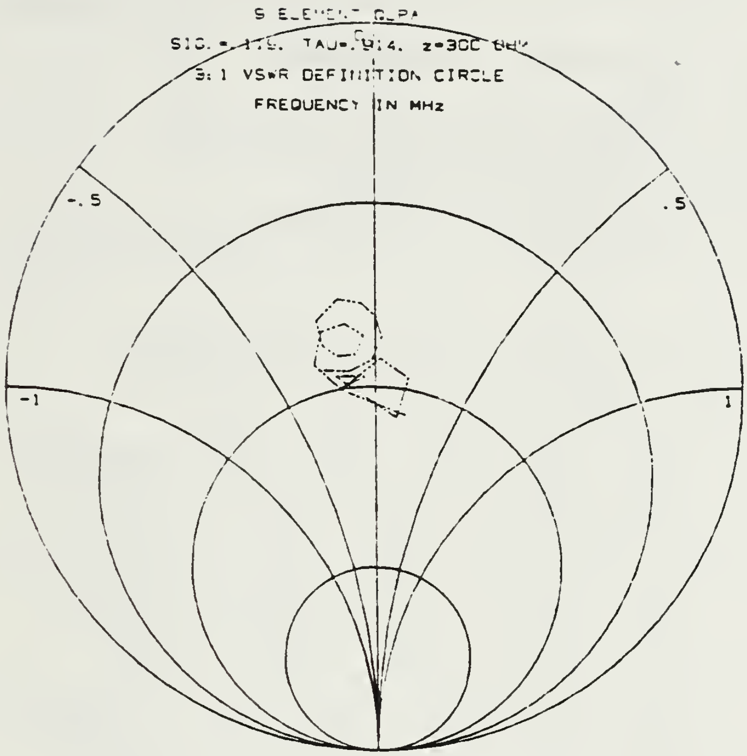
CURRENT PHASE

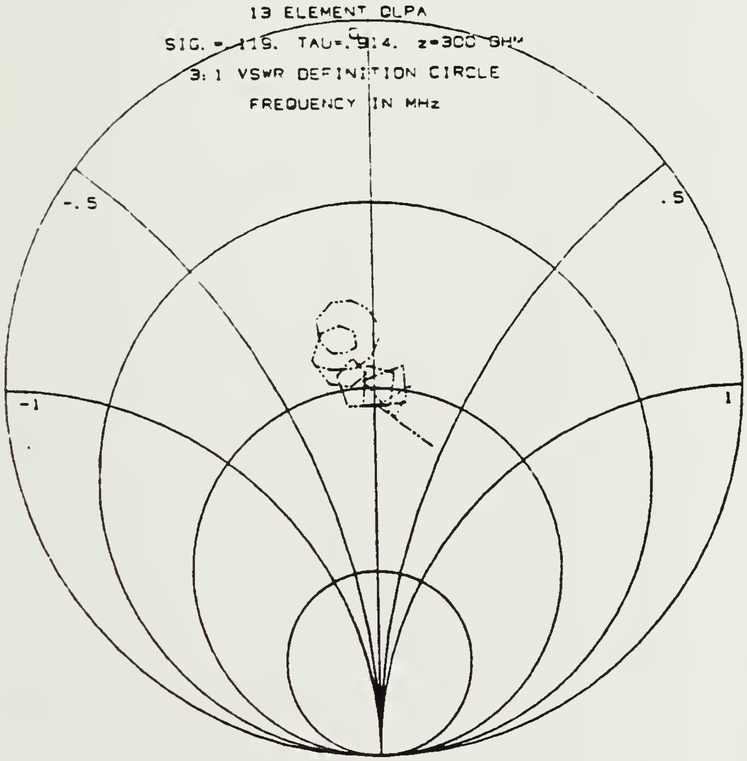


APPENDIX G. INPUT IMPEDANCE OF A QLPA






5 ELEMENT OLPA
SIG. = .119. TAU=.914. z=300 OHM
3:1 VSWR DEFINITION CIRCLE
FREQUENCY IN MHz
-.5
.5
-1
1


13 ELEMENT OLPA
SIG. = .119. TAU=.914. z=300 OHM
3:1 VSWR DEFINITION CIRCLE
FREQUENCY IN MHz
-.5
.5
-1
1

APPENDIX H. NEC DATA FILE FOR A QUPA

```
CM QUAD UNIFORM ARRAY (10 ELEMENTS)
CM IN FREE SPACE
CM VARIOUS FREQUENCIES (F = 150-650 MHZ)
CM DISTANCE BETWEEN ELEMENTS (D=.25M)
CM HORIZONTAL RADIATION PATTERNS
CM TRANSMISSION LINE (Z = 300 OHM SWITCHED FEED)
CM ANTENNA CICUMFERENCE 1M (EACH ELEMENT)
CE
GW 1,5,0,.125,-.125,0,-.125,-.125,0.000814
GW 2,5,0,-.125,-.125,0,-.125,.125,0.000814
GW 3,5,0,-.125,.125,0,.125,.125,0.000814
GW 4,5,0,.125,.125,0,.125,-.125,0.000814
GW 5,5,.25,.125,-.125,.25,-.125,-.125,0.000814
GW 6,5,.25,-.125,-.125,.25,-.125,.125,0.000814
GW 7,5,.25,-.125,.125,.25,.125,.125,0.000814
GW 8,5,.25,.125,.125,.25,.125,-.125,0.000814
GW 9,5,.5,.125,-.125,.5,-.125,-.125,0.000814
GW 10,5,.5,-.125,-.125,.5,-.125,.125,0.000814
GW 11,5,.5,-.125,.125,.5,.125,.125,0.000814
GW 12,5,.5,.125,.125,.5,.125,-.125,0.000814
GW 13,5,.75,.125,-.125,.75,-.125,-.125,0.000814
GW 14,5,.75,-.125,-.125,.75,-.125,.125,0.000814
GW 15,5,.75,-.125,.125,.75,.125,.125,0.000814
GW 16,5,.75,.125,.125,.75,.125,-.125,0.000814
GW 17,5,1.0,.125,-.125,1.0,-.125,-.125,0.000814
GW 18,5,1.0,-.125,-.125,1.0,-.125,.125,0.000814
GW 19,5,1.0,-.125,.125,1.0,.125,.125,0.000814
GW 20,5,1.0,.125,.125,1.0,.125,-.125,0.000814
GW 21,5,1.25,.125,-.125,1.25,-.125,-.125,0.000814
GW 22,5,1.25,-.125,-.125,1.25,-.125,.125,0.000814
GW 23,5,1.25,-.125,.125,1.25,.125,.125,0.000814
GW 24,5,1.25,.125,.125,1.25,.125,-.125,0.000814
GW 25,5,1.5,.125,-.125,1.5,-.125,-.125,0.000814
GW 26,5,1.5,-.125,-.125,1.5,-.125,.125,0.000814
GW 27,5,1.5,-.125,.125,1.5,.125,.125,0.000814
GW 28,5,1.5,.125,.125,1.5,.125,-.125,0.000814
GW 29,5,1.75,.125,-.125,1.75,-.125,-.125,0.000814
GW 30,5,1.75,-.125,-.125,1.75,-.125,.125,0.000814
GW 31,5,1.75,-.125,.125,1.75,.125,.125,0.000814
GW 32,5,1.75,.125,.125,1.75,.125,-.125,0.000814
GW 33,5,2.0,.125,-.125,2.0,-.125,-.125,0.000814
GW 34,5,2.0,-.125,-.125,2.0,-.125,.125,0.000814
GW 35,5,2.0,-.125,.125,2.0,.125,.125,0.000814
GW 36,5,2.0,.125,.125,2.0,.125,-.125,0.000814
GW 37,5,2.25,.125,-.125,2.25,-.125,-.125,0.000814
GW 38,5,2.25,-.125,-.125,2.25,-.125,.125,0.000814
GW 39,5,2.25,-.125,.125,2.25,.125,.125,0.000814
GW 40,5,2.25,.125,.125,2.25,.125,-.125,0.000814
GE
```

```
TL 1,3,5,3,-300, ,0,0,0,0
TL 5,3,9,3,-300, ,0,0,0,0
TL 9,3,13,3,-300, ,0,0,0,0
TL 13,3,17,3,-300, ,0,0,0,0
TL 17,3,21,3,-300, ,0,0,0,0
TL 21,3,25,3,-300, ,0,0,0,0
TL 25,3,29,3,-300, ,0,0,0,0
TL 29,3,33,3,-300, ,0,0,0,0
TL 33,3,37,3,-300, ,0,0,0,0
EX 0,1,3,0,1,0
FR 0,0,0,0,150
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,200
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,250
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,280
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,290
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,300
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,310
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,320
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,330
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,340
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
```

```
FR 0,0,0,0,350
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,360
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,380
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,400
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,425
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,450
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,475
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,500
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,525
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,550
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,580
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,590
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
FR 0,0,0,0,650
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
EN
```

```
CM QUAD UNIFORM ARRAY (10 ELEMENTS)
CM IN FREE SPACE
CM VARIOUS FREQUENCIES (F = 150-650 MHZ)
CM  DISTANCE BTN ELEMENTS (D=.3M)
CM  NEAR FIELD CONDITIONS
CM  DISTANCE 5R OUT OF THE WIRE (Z=.129884)
CM  TRANSMISSION LINE (Z = -180 OHM)
CM  ANTENNA CICUMFERENCE 1M
CE
GW 1,5,0,.125,-.125,0,-.125,-.125,0.000814
GW 2,5,0,-.125,-.125,0,-.125,.125,0.000814
GW 3,5,0,-.125,.125,0,.125,.125,0.000814
GW 4,5,0,.125,.125,0,.125,-.125,0.000814
GW 5,5,.3,.125,-.125,.3,-.125,-.125,0.000814
GW 6,5,.3,-.125,-.125,.3,-.125,.125,0.000814
GW 7,5,.3,-.125,.125,.3,.125,.125,0.000814
GW 8,5,.3,.125,.125,.3,.125,-.125,0.000814
GW 9,5,.6,.125,-.125,.6,-.125,-.125,0.000814
GW 10,5,.6,-.125,-.125,.6,-.125,.125,0.000814
GW 11,5,.6,-.125,.125,.6,.125,.125,0.000814
GW 12,5,.6,.125,.125,.6,.125,-.125,0.000814
GW 13,5,.9,.125,-.125,.9,-.125,-.125,0.000814
GW 14,5,.9,-.125,-.125,.9,-.125,.125,0.000814
GW 15,5,.9,-.125,.125,.9,.125,.125,0.000814
GW 16,5,.9,.125,.125,.9,.125,-.125,0.000814
GW 17,5,1.2,.125,-.125,1.2,-.125,-.125,0.000814
GW 18,5,1.2,-.125,-.125,1.2,-.125,.125,0.000814
GW 19,5,1.2,-.125,.125,1.2,.125,.125,0.000814
GW 20,5,1.2,.125,.125,1.2,.125,-.125,0.000814
GW 21,5,1.5,.125,-.125,1.5,-.125,-.125,0.000814
GW 22,5,1.5,-.125,-.125,1.5,-.125,.125,0.000814
GW 23,5,1.5,-.125,.125,1.5,.125,.125,0.000814
GW 24,5,1.5,.125,.125,1.5,.125,-.125,0.000814
GW 25,5,1.8,.125,-.125,1.8,-.125,-.125,0.000814
GW 26,5,1.8,-.125,-.125,1.8,-.125,.125,0.000814
GW 27,5,1.8,-.125,.125,1.8,.125,.125,0.000814
GW 28,5,1.8,.125,.125,1.8,.125,-.125,0.000814
GW 29,5,2.1,.125,-.125,2.1,-.125,-.125,0.000814
GW 30,5,2.1,-.125,-.125,2.1,-.125,.125,0.000814
GW 31,5,2.1,-.125,.125,2.1,.125,.125,0.000814
GW 32,5,2.1,.125,.125,2.1,.125,-.125,0.000814
GW 33,5,2.4,.125,-.125,2.4,-.125,-.125,0.000814
GW 34,5,2.4,-.125,-.125,2.4,-.125,.125,0.000814
GW 35,5,2.4,-.125,.125,2.4,.125,.125,0.000814
GW 36,5,2.4,.125,.125,2.4,.125,-.125,0.000814
GW 37,5,2.7,.125,-.125,2.7,-.125,-.125,0.000814
GW 38,5,2.7,-.125,-.125,2.7,-.125,.125,0.000814
GW 39,5,2.7,-.125,.125,2.7,.125,.125,0.000814
GW 40,5,2.7,.125,.125,2.7,.125,-.125,0.000814
GE
```

```
TL 1,3,5,3,-180, ,0,0,0,0
TL 5,3,9,3,-180, ,0,0,0,0
TL 9,3,13,3,-180, ,0,0,0,0
TL 13,3,17,3,-180, ,0,0,0,0
TL 17,3,21,3,-180, ,0,0,0,0
TL 21,3,25,3,-180, ,0,0,0,0
TL 25,3,29,3,-180, ,0,0,0,0
TL 29,3,33,3,-180, ,0,0,0,0
TL 33,3,37,3,-180, ,0,0,0,0
EX 0,1,3,0,1,0
FR 0,0,0,0,150
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,200
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,250
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,280
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,300
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,320
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,340
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,360
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,380
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,400
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,425
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
```

```
XQ
FR 0,0,0,0,450
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,475
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,500
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,525
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,550
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,575
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,600
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
FR 0,0,0,0,620
PL 2,2,1,1
NH 0,10,1,1,0,0,.129884,.3,0,0
XQ
EN
```

APPENDIX I. NEC DATA FILE FOR A QLPA

```
CM QUAD  LOG PERIODIC ARRAY (13 ELEMENTS)
CM IN FREE SPACE
CM SIGMA = .125 , TAU = .915 , A = 5.4 DEG.
CM ARRAY LENGTH : 2.771 M.
CM VARIOUS FREQUENCIES (F = 150-610 MHZ)
CM HORIZONTAL RADIATION PATTERNS
CM  TRANSMISSION LINE (Z = 300 OHM SWITCHED)
CE
GW 1,5,0,.0647,-.0647,0,-.0647,-.0647,0.000814
GW 2,5,0,-.0647,-.0647,0,-.0647,.0647,0.000814
GW 3,5,0,-.0647,.0647,0,.0647,.0647,0.000814
GW 4,5,0,.0647,.0647,0,.0647,-.0647,0.000814
GW 5,5,.135,.0707,-.0707,.135,-.0707,-.0707,0.000814
GW 6,5,.135,-.0707,-.0707,.135,-.0707,.0707,0.000814
GW 7,5,.135,-.0707,.0707,.135,.0707,.0707,0.000814
GW 8,5,.135,.0707,.0707,.135,.0707,-.0707,0.000814
GW 9,5,.283,.0773,-.0773,.283,-.0773,-.0773,0.000814
GW 10,5,.283,-.0773,-.0773,.283,-.0773,.0773,0.000814
GW 11,5,.283,-.0773,.0773,.283,.0773,.0773,0.000814
GW 12,5,.283,.0773,.0773,.283,.0773,-.0773,0.000814
GW 13,5,.445,.0845,-.0845,.445,-.0845,-.0845,0.000814
GW 14,5,.445,-.0845,-.0845,.445,-.0845,.0845,0.000814
GW 15,5,.445,-.0845,.0845,.445,.0845,.0845,0.000814
GW 16,5,.445,.0845,.0845,.445,.0845,-.0845,0.000814
GW 17,5,.622,.0923,-.0923,.622,-.0923,-.0923,0.000814
GW 18,5,.622,-.0923,-.0923,.622,-.0923,.0923,0.000814
GW 19,5,.622,-.0923,.0923,.622,.0923,.0923,0.000814
GW 20,5,.622,.0923,.0923,.622,.0923,-.0923,0.000814
GW 21,5,.815,.1009,-.1009,.815,-.1009,-.1009,0.000814
GW 22,5,.815,-.1009,-.1009,.815,-.1009,.1009,0.000814
GW 23,5,.815,-.1009,.1009,.815,.1009,.1009,0.000814
GW 24,5,.815,.1009,.1009,.815,.1009,-.1009,0.000814
GW 25,5,1.026,.1103,-.1103,1.026,-.1103,-.1103,0.000814
GW 26,5,1.026,-.1103,-.1103,1.026,-.1103,.1103,0.000814
GW 27,5,1.026,-.1103,.1103,1.026,.1103,.1103,0.000814
GW 28,5,1.026,.1103,.1103,1.026,.1103,-.1103,0.000814
GW 29,5,1.257,.1205,-.1205,1.257,-.1205,-.1205,0.000814
GW 30,5,1.257,-.1205,-.1205,1.257,-.1205,.1205,0.000814
GW 31,5,1.257,-.1205,.1205,1.257,.1205,.1205,0.000814
GW 32,5,1.257,.1205,.1205,1.257,.1205,-.1205,0.000814
GW 33,5,1.509,.132,-.132,1.509,-.132,-.132,0.000814
```

```
GW 34,5,1.509,-.132,-.132,1.509,-.132,.132,0.000814
GW 35,5,1.509,-.132,.132,1.509,.132,.132,0.000814
GW 36,5,1.509,.132,.132,1.509,.132,-.132,0.000814
GW 37,5,1.784,.1443,-.1443,1.784,-.1443,-.1443,0.000814
GW 38,5,1.784,-.1443,-.1443,1.784,-.1443,.1443,0.000814
GW 39,5,1.784,-.1443,.1443,1.784,.1443,.1443,0.000814
GW 40,5,1.784,.1443,.1443,1.784,.1443,-.1443,0.000814
GW 41,5,2.085,.1577,-.1577,2.085,-.1577,-.1577,0.000814
GW 42,5,2.085,-.1577,-.1577,2.085,-.1577,.1577,0.000814
GW 43,5,2.085,-.1577,.1577,2.085,.1577,.1577,0.000814
GW 44,5,2.085,.1577,.1577,2.085,.1577,-.1577,0.000814
GW 45,5,2.413,.1723,-.1723,2.413,-.1723,-.1723,0.000814
GW 46,5,2.413,-.1723,-.1723,2.413,-.1723,.1723,0.000814
GW 47,5,2.413,-.1723,.1723,2.413,.1723,.1723,0.000814
GW 48,5,2.413,.1723,.1723,2.413,.1723,-.1723,0.000814
GW 49,5,2.771,.1883,-.1883,2.771,-.1883,-.1883,0.000814
GW 50,5,2.771,-.1883,-.1883,2.771,-.1883,.1883,0.000814
GW 51,5,2.771,-.1883,.1883,2.771,.1883,.1883,0.000814
GW 52,5,2.771,.1883,.1883,2.771,.1883,-.1883,0.000814
GE
TL 1,3,5,3,-300, ,0,0,0,0
TL 5,3,9,3,-300, ,0,0,0,0
TL 9,3,13,3,-300, ,0,0,0,0
TL 13,3,17,3,-300, ,0,0,0,0
TL 17,3,21,3,-300, ,0,0,0,0
TL 21,3,25,3,-300, ,0,0,0,0
TL 25,3,29,3,-300, ,0,0,0,0
TL 29,3,33,3,-300, ,0,0,0,0
TL 33,3,37,3,-300, ,0,0,0,0
TL 37,3,41,3,-300, ,0,0,0,0
TL 41,3,45,3,-300, ,0,0,0,0
TL 45,3,49,3,-300, ,0,0,0,0
EX 0,1,3,0,1,0
FR 0,0,0,0,100
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,150
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,160
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,170
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,180
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
```

```
FR 0,0,0,0,190
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,200
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,210
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,220
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,230
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,240
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,250
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,260
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,270
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,280
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,290
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,300
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,310
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,320
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,330
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,340
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,350
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
```

```
FR 0,0,0,0,360
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,370
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,380
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,390
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,400
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,410
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,420
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,430
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,440
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,450
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,460
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,470
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,480
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,490
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,500
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,510
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
```

```
FR 0,0,0,0,520
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,530
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,540
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,550
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,560
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,570
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,580
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,590
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,600
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
FR 0,0,0,0,610
PL 3,2,0,4
RP 0,1,361,1501,90,0,0,1
XQ
EN
```

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Thesis
C4735 Christidis
c.1 A computer model investigation of a quad log-periodic array.